As per NEP 2020 Scheme Syllabus
w.e.f. Academic Year 2024-2025

UNIVERSITY of MUMBAI

First Year (F.E.) Degree Courses in Engineering
COMMON FOR ALL BRANCHES [Semester - II]

ENGINEERING MATERIALS

Dr. Mrs. TRUPTI S. PARADKAR

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NIRALI PRAKASHAN
ADVANCEMENT OF KNOWLEDGE

A TEXT BOOK OF

ENGINEERING MATERIALS

FOR
SEMESTER - II

F.E. DEGREE COURSES IN ENGINEERING
COMMON FOR ALL BRANCHES
(Code : BSC2031)

As per NEP 2020 Scheme Syllabus of
UNIVERSITY OF MUMBAI
w.e.f. Academic Year 2024-2025

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PREFACE

It gives me immense pleasure to present the first edition of the book on Engineering Materials to the First Year Engineering Students of all the branches. This book is prepared according to the Revised Syllabus of University of Mumbai (based on NEP 2020 Scheme) which comes into effect from the academic year 2024-2025.

The syllabus has been meticulously followed throughout the book with emphasis on minute details. The topics have been structured in order to develop the subject in a logical sequence. The coverage of this book will definitely help students to understand and grasp the subject with ease.

Numerous solved problems including the ones from university examinations of past years on different topics have been incorporated wherever applicable.

At the end of every chapter there are ample unsolved problems for practice along with answer keys. Review questions on theory have been added along with references to the appropriate sections in the book.

Any constructive suggestions for enhancing the utility of this book, and for removing errors that might have gone unnoticed will be gratefully acknowledged.

Author
Dr. (Mrs.) Trupti S. Paradkar

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I am also grateful to my husband Mr. Sanjay Paradkar and loving daughter Owee for bearing with me throughout this exercise.

Last but not the least, special thanks to my students for their overwhelming response to all my earlier books on Applied Chemistry & Engineering Chemistry.

Author
Dr. (Mrs.) Trupti S. Paradkar

DEDICATED
TO
MY
BELOVED MOTHER
GATHA
&
SUPPORTIVE HUSBAND
SANJAY

For their unconditional love and encouragement

SYLLABUS

Module 1 : Alloys — 04 Hours

- Ferrous alloys – Plain-carbon steels, Heat and Shock resisting steels, Stainless steels. Effect of the alloying element- Ni, Cr, Co, Mn, Mo, W and V.
- Aluminium alloys – Composition, properties and uses of i) Duralumin, ii) Magnalium.
- Copper alloys – Composition, properties and uses of i) Brass – Dutch Metal and German Silver and ii) Bronze – Gun metal and Nickel bronze.
- Alloys of Pb – Composition, properties and Uses of i) Wood's metal ii) Tinman's solder.
- Numerical based on Composition, density and weight of an alloy

Module 2 : Ceramics — 04 Hours

- Introduction of Ceramics – Definition, types, properties and uses.
- Glass – Definition, Properties, Types with uses.
- Abrasives – Natural and Artificial Abrasives – Examples, Properties and Uses.
- Optical fibres – Definition, Components of optical transmission system, Advantages of optical fibre communication, Applications of glass-based fibre - optical fibres.

Module 3 : Composites — 04 Hours

- Types of Composites, sub-types and Applications: - i) Fibre-reinforced composites, ii) Layered-composites (Laminates), iii) Particulate-composites.
- Bio-composites – Definition, Classification and Applications.

Module 4 : Plastics and Elastomers — 05 Hours

- Introduction to Plastics - Thermoplastic and Thermosetting plastics, compounding of plastics, Application of Plastics, Numerical based on Degree of polymerisation, Density and mass, tensile strength of polymer
- Introduction to Elastomers - structural requirement of elastomer, natural rubber, processing of natural rubber, drawbacks, compounding of rubber
- Synthesis of commercial polymers:
  i) Plastics: Preparation, properties and uses of Polymethyl Methacrylate (PMMA), polytetrafluoroethylene (PTFE)
  ii) Elastomers: Preparation, properties and uses of Polyurethane Rubber, Silicone rubber

Module 5 : Advanced Polymers — 03 Hours

- Conducting polymers,
- Bio-polymers,
- Liquid crystal polymers,
- Intelligent (smart) polymers.

Module 6 : Nanomaterials — 04 Hours

- Definition, Types of Nanostructured materials, Applications of Nanomaterials.
- Graphene,
- Types of Carbon Nanotubes (SWCNTs and MWCNTs) – Properties and Uses.

TEACHING AND EXAMINATION SCHEME

Course code	Course Name	Teaching Scheme (Contact Hours)			Credits Assigned			
		Theory	Practical	Tutorial	Theory	Tutorial	Practical	Total
BSC2031	Engineering Materials	2	-	-	2	-	-	2

Course code	Course Name	Examination Scheme							
		Theory					Term work	Practical/ Oral	Total
		Internal Assessment			End Sem. Exam.	Exam. Duration (in Hrs.)			
		IAT-I	IAT-II	IAT-I + IAT-II (Total)					
BSC2031	Engineering Materials	15	15	30	45	2	-	-	75

ASSESSMENT

Internal Assessment Test (IAT) for 20 marks each:

IA will consist of Two Compulsory Internal Assessment Tests. Approximately 40% to 50% of the syllabus content must be covered in the IAT-I and the remaining 40% to 50% of the syllabus content must be covered in the IAT-II.

End Semester Theory Examination:

Question paper format

1. Question Paper will comprise a total of five questions each carrying 15 marks Q.1 will be compulsory and should cover the maximum contents of the syllabus
2. Remaining questions will be mixed in nature (part (a) and part (b) of each question must be from different modules. For example, if Q.2 has part (a) from Module 3 then part (b) must be from any other Module randomly selected from all the modules)
3. A total of three questions need to be answered

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CHAPTER 1

ALLOYS

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1.1 INTRODUCTION

A single metal has very limited properties and uses. Further, in nature, metals are rarely available in pure state. Pure metals are soft, chemically reactive, high melting and less corrosion resistant. Further they do not possess the properties generally required for engineering purposes. The properties of any metal can be modified by alloying with one or more elements to develop the desired properties in it. The element present in largest proportion is a metal and the others are metals or non-metals. The element, which is present in the largest amount, is called the base metal or parent metal or solvent and the other elements are called alloying elements or solvents. Thus, alloy may be defined as a solid solution, in which the solutes are the alloying elements and the solvents are the base element in excess proportion. In alloys, the chemical properties of constituent elements are retained while physical properties are improved.

An alloy system can be formed by several elements combined in all possible proportions. When the system is made up of two elements, it is called binary alloy system. Similarly, ternary, quaternary etc. can be made up from three, four elements etc., respectively.

Metals and alloy are used in various forms for various purposes. For example, they are used for agricultural purpose, in automobiles, building and bridge construction, shipping and transportation, light and heavy machinery and equipment and even in advanced aircrafts. They have occupied an important place and have become backbone of all engineering projects and products.

Definition :

An alloy is an intimate mixture of two or more elements, out of which one must be a metal.

Alloys are formed not only by metals among themselves, but also by metals and non-metal. The common metals present in alloy system are copper, zinc, lead, tin, nickel, aluminium, chromium, tungsten etc. and the non-metals are carbon, boron, sulphur, phosphorous etc.

1.2 TYPES OF ALLOYS

Alloys may be classified in a number of ways :

(1) Based on the principal metal in the alloy : Alloys can be classified on the basis of the principal metal in the alloy. For example :

Copper alloys (copper is main constituent e.g. Bronze), Aluminium alloys (aluminium is main constituents e.g. Duralumin), Lead alloys (e.g. solders), Iron alloys (e.g. stainless steel, iron is main constituent).

(2) Based on phases :

For example, Single-phase alloys consists of a uniform phase.

For example : Brass (Cu = 70% + Zn = 30%).

Monel metal (Ni = 66% + tin = 34%)

Two phase alloys : For example, Muntz metal (Zn = 40% + Cu = 60%).

(3) Based on iron content :

Alloys can be classified on the basis of its principle constituent of its alloy as :

(i) Ferrous alloys : These alloys contain iron as a major constituent. For example, stainless steel, tool steels, alloy steels etc.

(ii) Non-ferrous alloys : These alloys do not contain iron as a major constituent but contain non-ferrous metals like copper, aluminium, zinc, nickel, tin, lead etc. These metals and their alloys are several times more expensive than the ferrous materials.

Some of the more common alloys are : alloys of copper, alloys of lead, alloys of aluminium, alloys of nickel, alloys of tin etc.

(4) Based on application : Classification can be done on the basis of the purpose for which they are used. For example, solders, bearing alloy etc.

1.3 FERROUS ALLOYS

In ferrous alloys, iron is the prime constituent. They are important in engineering construction materials. They can be grouped into plain carbon steels and alloy steels.

1.3.1 Plain Carbon Steels

Steel is essentially iron and carbon. The carbon content of these alloys varies from 0.15% to 1.5%. All the distinctive properties of plain carbon steels are determined by the presence of carbon content. In addition to carbon, they may contain manganese (upto 1%), sulphur (upto 0.3%), silicon (upto 0.03%) and phosphorous (upto 0.5%).

Functions of Carbon in Steels :

It is now well established that carbon is responsible for the property of steel.

(1) The strength of the steel increases with the increase in the proportion of carbon till it reaches 0.83%. After that, the effect is in the reverse direction.

(2) The ductility decreases with increase in carbon content. It affects the workability of the steel.

(3) The hardness of the steel increases with increased amount of carbon.

(4) The susceptibility to heat treatment increases with increased carbon content.

With all these effects, even in the highest carbon steels, extent of carbon required to be present should not be more than 1.5%.

1.3.2 Limitations of Plain Carbon Steels

(1) The corrosion resistance of plain carbon steels is very low. As a result, it has limited use in manufacturing various machine parts inspite of good strength and welding characteristics.

(2) With increasing percentages of carbon, the ductility decreases and brittleness increases.

(3) On heat treatment, the plain carbon steels can not be deep hardened.

(4) The use of plain carbon steels has limitation of temperature as the mechanical properties of plain carbon steels get deteriorated at higher temperature.

1.3.3 Classification of Steels Depending upon Carbon Content

Depending upon carbon content, steels are classified as follows :

(A) Mild steels (carbon 0.15 to 0.3%)

(B) Medium steels (carbon 0.3 to 0.8%)

(C) High steels (carbon 0.8 to 1.5%)

(A) Mild Steels : In mild steels, carbon content ranges from 0.15 to 0.3 percent. It is also called low carbon steel or soft steel. If the carbon content is 0.15 percent, then it is called 'dead mild' steel.

Properties :

(1) They are quiet tough and ductile.

(2) They are weldable by forging.

(3) They can withstand shock and impact.

(4) They are difficult to harden and temper.

(5) They can be permanently magnetized.

(6) They undergo corrosion very quickly.

(7) They have fibrous structure with dark bluish colour.

(8) They are not affected by saline water.

(9) Their density is about 7.8g cm^{-3}.

(10) Their strength is about 40 kg/mm^2.

Uses :

(1) Mild steel round bars are used for reinforcement in reinforced cement concrete. (RCC).

(2) Steels made of mild steel are used as roof covering.

(3) Mild steel is used for the manufacture of bolts, nuts, rivets, screws, plates for boilers and ships.

(4) It is also used in the manufacture of rail tracks, cranes, transmission towers, industrial building structures in the form of I-sections, T-sections, angle irons, plates, channel sections round and square rods.

(B) Medium Carbon Steels : These steels have carbon content between 0.3 to 0.8%.

Properties :

(1) They are tougher and harder and exhibit greater strength than mild steels.

(2) They are shock resistant.

(3) Like mild steels, they are not easily weldable.

(4) They can be hardened to some extent.

Uses :

(1) They are used for the manufacture of wheels, gears, wires, hammers, hydraulic fittings like cylinders, rams, shafts etc.

(2) They are also used in the manufacture of rifle barrels, gun parts, heavily stressed parts in general engineering, castings for automobile engine components.

(3) They are used to prepare wire ropes, steel spokes clutch plates, boiler marine shafts and axels, turbines disc, connecting rods, helical springs etc.

(C) High Carbon Steels : These steels have carbon content 0.8 to 1.5%. High carbon steel with carbon content over 1% is known as cast steel or carbon tool steel.

Properties :

(1) They have granular structure and can be permanently magnetized.

(2) They are hard and possess high strength.

(3) With increase in carbon content their hardness and strength increase; however ductility and wearability decrease.

(4) They can be hardened and tempered easily and can be hardened further by heating at high temperature.

(5) They can withstand shocks and vibrations better.

(6) They are resistant to wear.

(7) They are difficult to forge.

Uses :

(1) They are used in the manufacture of springs, blades, chisels, hammers, dies, cutters, saw drills, files, wood working tools, metal cutting tools etc.

(2) They are used in the manufacturing of gauges, boring tools, screw drivers, safes, mandrels, engraving tools etc.

1.3.4 Effects of Different Elements Present in the Steel

In addition to iron and carbon, carbon steels contain other elements such as silicon, sulphur, phosphorous and manganese. It is necessary to understand the effects of each element and changes in the properties in the selections of steel for specified purposes.

(1) **Manganese :** It is most important element present in the steel. It is a valuable deoxidizing and purifying agent. It deoxidizes harmful ferrous oxide. It combines with sulphur to form harmless manganese sulphide and thus decreases harmful effects of sulphur. It increases ductility and bending qualities of steel. Presence of manganese more than 1% increases tensile strength and hardness of the steel.

(2) **Silicon :** It is used in steel manufacture as a scavenger. It makes the metal sound and free from blow holes by eliminating gases. Its presence improves the tensile strength and deep hardening properties. Only small amount of silicon is added, a fraction of that added is found in the finished steel, seldom exceeding 0.25%.

(3) **Sulphur :** In all steels, it is kept low as it is a valueless to the metal. It is present in steel either in the form of manganese sulphide or iron sulphide. Its total content should not exceed 0.06%; otherwise steel becomes brittle and red short. It also affects tensile strength, yield point, fatigue limit and decreases corrosion resistance.

(4) **Phosphorus :** Phosphorus should not be present above 0.06 percent as it imparts high brittleness at low temperatures. It increases tensile strength but reduces impact strength and ductility. The sum of carbon and phosphorus should not exceed 0.3 percent. In low carbon steels, phosphorus improves yield strength and tensile strength.

1.4 ALLOY STEELS

We have already discussed that plain carbon steel finds only limited use. Additions of small amounts of one or more metals such as nickel, cobalt, chromium etc. is carried out to impart special properties to the steel. Such steels are known as alloy steels or special steels or simply we can say that **alloy steels** are the steels containing other elements like Ni, Mn, Cr, W etc. which are added to plain carbon steels for enhancement of their one or more properties.

1.4.1 Purposes of Making Alloy Steels

The main purposes of making alloy steels are :

(1) To improve the tensile strength.

(2) To improve the ability to retain physical properties at high temperatures.

(3) To improve ductility, malleability and elasticity.

(4) To improve toughness and hardness.

(5) To improve corrosion and heat and shock resistance.

(6) To improve hardenability.

(7) To increase resistance to abrasion.

(8) To improve acid and chemical resisting property.

(9) To minimize the coefficient of expansion.

(10) To improve the ability to retain the shape in hot condition.

(11) To improve the ability to undergo milling operations smoothly.

(12) To increase magnetic permeability.

(13) To improve cutting ability and weldability.

(14) To improve red hardness.

1.4.2 Special Effects of Alloying Elements on the Properties of Steel

The properties of steels are greatly affected by the presence of alloying elements. A brief description of their effects is summarized in the following table :

Table 1.1 : Effect of Alloying Elements

Alloying Element	Properties imparted to steel
(1) Nickel (Ni)	Improves tensile strength, ductility, toughness, elasticity, heat and corrosion resistance.
(2) Chromium (Cr)	Improves tensile strength, hardness, wear resistance and toughness. Imparts high corrosion resistance
(3) Molybdenum (Mo)	Increases strength at elevated temperature, corrosion and abrasion resistance. Temper brittleness is eliminated.
(4) Tungsten (W)	Improves Red hardness, toughness, abrasion resistance and shock resistance.

(5) Vanadium (V)	Increases ductility, tensile strength, shock resistance and impact resistance.
(6) Manganese (Mn)	Improves strength toughness and brittleness. Provides high degree of hardness, non-magnetic, highly wear resistant.
(7) Silicon (Si)	Increases strength without decreasing ductility. Very hard, good castability and increases corrosion resistance.
(8) Cobalt (Co)	High magnetism and hardness, cutting and drilling ability at high speeds.

1.4.3 Application of Alloy Steels

On the basis of particular type of their use, alloy steels (special steels) have different applications which are described as follows :

(1) Heat Resisting Steels :

Heat resisting steels are the alloy steels suitable for making equipments which are suitable for working at high temperatures. They contain approximately 3.5% molybdenum, more than 12% chromium and up to 0.15% carbon.

All heat resisting steels contain chromium as universal constituent as it increases corrosion resistance at high temperature. It generally contains more than 12% chromium. Molybdenum is another important alloying element which gives strength and creep resistance to steel at high temperatures. Carbon percentage in heat resisting steel is kept low so that at high temperature, brittleness will not be introduced due to carbide precipitation. Nickel decreases coefficient of expansion.

Uses :

Heat resisting steels are used for making furnace parts, gas turbine, boiler parts, retorts, combustion chamber of petrol and diesel engine, aero-engine valves and other equipment which are exposed to high temperatures.

(2) Nichrome :

Nichrome steel is an important heat resisting alloy steels. It is probably the most widely used of all alloy steels. There are a large number of heating devices which require special materials for conversion of electrical energy into heat. Nichrome steels are used in such devices.

(i) Steel alloyed with 60% nickel and 12% chromium can be used at 1000 to 1100°C.

(ii) Steels containing 16 to 20 percent chromium with low (0.06 to 0.15%) carbon possess oxidation resistance up to 900°C.

(iii) Steels containing 18% nickel with small amounts of columbium can withstand temperature as high as 900°C.

Properties :

(1) It has high resistance to oxidation.

(2) It has sufficient strength at high operating temperatures and good resistivity.

(3) It has high hardenability and very high mechanical property.

Uses :

(1) It is used in making parts of boilers, steam lines, stills, gas turbines and aero-engine valves.

(2) It is used in manufacture of retorts, annealing boxes and other equipment exposed to high temperature.

(3) Stainless Steels or Corrosion Resistant Steels :

These are the alloy steels which resist corrosion. They do not get corroded by the environmental conditions and also by chemicals. So, they are called stainless steels or corrosion resistant steels. They contain the element chromium which is having high corrosion resistivity. Chromium is especially effective, if its content is 16 percent or more. The other elements present along with chromium are nickel, molybdenum etc. These steels are very slightly oxidisable. The protection against corrosion is due to formation of dense, tough film of chromium oxide at the surface of the metal. This film formed is non-porous, chemically inert and protective. If this film is broken in service, it gets healed up automatically by oxygen of air. The protective film of chromium oxide is so thin that the colour and beauty of the basic material is not affected. There are two main types of stainless steels :

(a) Heat treatable stainless steels :

They contain up to 1.2 percent carbon and less than 18 percent chromium (generally 12 to 16 percent).

Properties :

(1) They are magnetic, tough and can be worked in cold state.

(2) They can be used at temperature upto 800°C.

(3) They are satisfactory for resisting weather and water.

Use :

(1) These steels are used in making surgical instruments, scissors, blades, cutlery etc.

(b) Non heat treatable stainless steels :

These steels show less strength at high temperatures. They are more resistant to corrosion. Depending on their composition, they may be further classified as:

(i) **Magnetic stainless steels :** They contain 12-22 percent chromium, with carbon content below 0.35%. They can be forged, rolled or cold drawn and machined by the use of specially designed tools. They possess better corrosion resistance than heat treatable ones. They are used in making chemical equipments and automobile parts.

(ii) **Non-magnetic stainless steels :** They contain 18 to 26 percent chromium, 8 to 21 percent nickel and upto 0.15% carbon. Total percentage of chromium and nickel is more than 23 percent. These steels exhibit maximum corrosion resistivity. To improve the corrosion resistivity, a little quantity of molybdenum is added. Most widely used common stainless steel contains 18 percent chromium and 8 percent nickel and is referred to as **'18/8 stainless steels'** which are extremely tough, ductile, strong and highly corrosion resistant.

These steels are used in making household utensils, decorative pieces, skins, dental instruments, surgical instruments etc.

1.4.4 Advantages and Disadvantages of Alloy Steels

Advantages :

(i) Possess greater hardenability and greater ductility at high strength.

(ii) Better machinability at high hardness.

(iii) Greater high temperature strength.

Disadvantages :

(i) High cost and requires special handling.

(ii) Temper brittleness in certain grades of alloy steels.

1.5 NON-FERROUS ALLOYS

Steel and other ferrous alloys are consumed in very large quantities because they have very wide range of mechanical properties, they may be fabricated with relative ease and are economical to produce. Ferrous alloys are associated with certain limitations such as a relatively high density, a comparatively low electrical conductivity and an inherent susceptibility to corrosion. Thus, for many applications, it is advantageous or necessary to use non-ferrous alloys (alloys of base metals such as copper, aluminium, manganese and titanium etc.)

The alloys are of two types, cast and wrought alloys. Alloys that are so brittle that forming or shaping by appreciable deformation is not possible ordinarily are cast alloys

On the other hand, those that are amenable to mechanical deformation are termed wrought alloys. A heat treatable alloy means one whose mechanical strength is improved by some specific heat treatment. While quoting the composition of aluminium, magnesium and titanium alloys, the base metal content is not mentioned in percentage composition, the balance content is base metal composition.

They find wide applications because of their following properties :

(1) Alloys have attractive colours.

(2) They have good formability.

(3) They possess softness.

(4) They possess special electrical properties.

(5) They are workable at low temperatures.

(6) They show magnetic properties.

(7) They are castable easily.

(8) They have low coefficient of friction.

(9) They have low density.

(10) They have good resistance to atmospheric corrosion.

1.5.1 Alloys of Aluminium

In general, aluminium alloys have one or more of the following properties and hence used very widely in engineering industry :

(1) They are light in weight.

(2) They possess excellent corrosion resistance.

(3) They have high thermal and electrical conductivity.

(4) They are malleable and ductile.

(5) They can be cast, forged, welded, extruded, rolled etc.

(6) Some of them are more than four times as strong as the same weight of mild steel.

Uses of Aluminum and Aluminium Alloys :

The intensive demand for aluminium and its alloy is due to their physical, mechanical and chemical properties. Aluminium and its alloys are used for the following :

(1) **Transportation industry :** To make structural frame-work, engines parts, trim and decorative features, hardware, doors, window frames, tanks, furnishing and fittings. In trucks, buses, trains, automobile cars and aeroplanes accessories and in their component equipment, refrigeration, storage containers, bakery equipment, shipping container etc.

(2) **In food industry :** Aluminium alloys find applications as food preparation equipment. This is because of their non-toxic nature.

(3) **In architectural field :** Aluminium alloys find uses such as window frames, doors hardware, roofing, coping sills, railing, fasteners, lighting fixtures, solar shadings, grill because these alloys are highly malleable and ductile.

(4) **In heavy duty structures :** They are used in structures such as traveling cranes, hoists, conveyor support, bridges etc. because these alloys are tough and strong at lower temperatures.

(5) **In process industries :** Parts made up of aluminium and its alloys are used to handle organic chemicals, petrochemicals and drugs. Tanks, drums, pipes, heat exchangers, grating, smock-stacks, precipitators, centrifuges, valves, fittings etc. are produced from aluminium alloys, because the passivation of aluminum makes its alloy highly useful even in chemical industries.

(6) **Overhead conductors and heat exchange parts :** These are also made from aluminium alloys. Theses alloys find cryogenic applications too.

Some important alloys of aluminium are as follows :

(1) Duralumin : It is most widely used alloy of aluminium.

Composition : It contains Al = 95%, Cu = 4%, Mn = 0.5%, Mg = 0.5%.

Properties :

(i) It is light weighted, tough, highly ductile.

(ii) It is good conductor of heat and electricity.

(iii) It possesses good strength and corrosion resistance.

(iv) It can easily be worked as it possesses high machinability.

(v) It approaches mild steel in strength and yet its density is $1/3^{rd}$ of steel.

Uses :

(i) Due to high strength with low density, it finds extensive use in aircraft industry in the form of a 'clad'.

(ii) It is also used in making surgical instruments, cables, fluorescent tube caps etc.

(iii) It is used in making automobile and locomotive parts because of its high ductility and good electrical conductivity.

(2) Magnalumin :

Composition : It contains about Al = 70-90% and Mg = 30-10%.

Properties :

(i) It is lighter, strong, tough than pure aluminium.

(ii) It possesses similar mechanical properties like brass.

(iii) It possesses good corrosion resistance.

Uses :

(i) It is used for making balances, airplanes parts and scientific instruments.

(ii) It is also used in automobile components, diary equipment and architectural work.

1.5.2 Alloys of Copper

These are the alloys in which copper is the main constituent. Copper and its alloys rank next to steel as engineering materials. Copper alloys normally possess excellent corrosion resistance, electrical and thermal conductivity and formability. Some copper alloys are used for marine applications. Because of their wearing properties and high hardness, they are used as surfacing metals. They are selected for decorative applications. Copper may be alloyed with large number of elements; the most common are zinc, tin, aluminium and nickel. The solid solution of all these alloys is considerably tough and ductile. Copper mainly forms an alloy with materials like tin (bronze), zinc (brass) and nickel (cupronickel).

Brasses and Bronzes are the most important alloys of copper which are extensively used. Numerous modifications have been made in these types of alloys by using major constituents of elements in different proportions and also contain small amounts of other elements to make it suitable for specific purpose. These are termed as modified brasses and bronzes.

(A) Brass :

Brass is an alloy of copper and zinc. The properties of brass varies with the percentage of zinc. Brass containing lower percentage of zinc is softer. Those containing more percentage of zinc are harder and are important from engineering point of view. Besides zinc, small quantities of other metals like iron, tin, nickel, lead etc. are added to impart certain properties to brass.

Copper-zinc alloys containing 20-45% zinc are called brasses. Most commercial brasses contain up 40% zinc, since alloys having more than 40% zinc are brittle. Brasses with less than 25% zinc are called low brasses and are used for ornamental and decorative ware because of their pleasing reddish colour. The brasses containing more than 25% zinc are called high brasses. High brasses are cheaper than low brasses as copper is costlier than zinc. Higher brasses are of chemical importance. Besides zinc other elements are added in small amounts so as to make the brass suitable for a specific purposes. Addition of zinc up to 30% increases its tensile strength and ductility.

Brasses have greater strength than copper metal and by adding appropriate quantities of other metals improve mechanical properties such as ductility, strength, machinability etc. Corrosion and abrasion resistance of brass is increased by addition of small quantities of tin.

Some important types of brasses are as follows :

(1) Dutch Metal (low brass) :

Composition : It contains Cu = 80% and Zn = 20%.

Properties :

(i) It is golden in colour.

(ii) It is suitable for all drawing and forming operations.

Uses :

(i) It is used in making musical instruments, flexible hoses, tubes, name plates etc.

(ii) It is used in cheap jewellery.

(2) German silver (Nickel silver) :

Composition : It contains Cu = 25-50%, Zn = 10-35% and Sn = 5-35%.

Properties :

(i) It has very good mechanical properties and corrosion resistance.

(ii) It is extremely ductile and malleable.

(iii) It has high tensile strength.

(iv) It gives silvery colour.

Uses :

(i) It is used for decorative and architectural purposes.

(ii) It is used for making tableware and cutlery.

(iii) It is used for making coins, marine fixtures, household utensils, resistance wire and coils.

(B) Bronze :

Bronze is an alloy of copper and tin. Bronzes are stronger and harder than brasses. Bronzes are expensive and superior to brass. Tin content varies from 2 to 12% but generally bronzes have 5% and 10% tin commonly used. Bronzes are classified as :

Wrought bronzes and Cast bronzes :

Wrought bronzes contain tin up to 8% and can be easily worked mechanically both cold and hot. Cast bronzes contain tin up to 12% and are excellent foundary materials they fill moulds well and shrinks on solidification to a small extent.

Bronze is most ductile when it contains about 5% tin and ductility gradually decreases with increase in tin content.

Some important types of bronzes are as follows :

(1) Gun metal :

Composition : It contains Cu = 85%, Zn = 4%, Sn = 8% and Pb = 3%.

Properties :

(i) It is hard, tough.

(ii) It is strong to resist the force of explosion.

Properties :

(i) It is used in foundry works, hydraulic fittings and heavy load bearings.

(ii) It is used in parts of high-pressure steam plants, water fittings, marline pumps etc.

(2) Nickel bronze :

Composition : It contains Cu = 90%, Ni = 9%, Fe = 1%.

Properties :

(i) It is hard and higher in tensile strength.

(ii) They are better corrosion resistant than copper.

Uses :

(i) It is used for making general purpose semi-hard bearings, un-hardened shafts and valves.

(ii) It is used for rolling purposes.

Comparison :

Brass	Bronze
1. Brasses are alloys of copper and zinc.	1. Bronzes are alloys of copper and tin.
2. Inferior to bronze in respect of corrosion resistance.	2. Superior to brass in respect of corrosion resistance.
3. Less stronger and harder than bronze.	3. More stronger and harder than brass.
4. Because of high toughness, common grades of brass are difficult to machine.	4. They can be machined easily.
5. Other elements present in brass are tin, Mn, Al, Fe, Pb, etc	5. Other elements present in bronze are Al, P, Be, Si, etc
6. The various types of brasses are commercial brass, cartridge brass, German silver etc.	6. The various types of bronzes are gun-metal, Al-bronze, Ni-bronze etc.
7. Brasses are cheap because of zinc content.	7. Bronzes are more expensive because of tin content.

1.5.3 Alloys of Lead

It is an important alloy of lead and tin. They have good flow characteristics and hence they are used as solders. They are used for joining two metals. Solders melt at a lower temperature than the metals to be joined or soldered. When an alloy with a lower melting point is used for joining metals, the process is known as soldering and when an alloy with higher melting point is used for joining metals, the process is known as brazing. Soldering is most frequently used for electrical and electronic assemblies which account for almost half of all soldering activities.

Some important types of solders are as follows

(1) Tinman's solder (quick solder) :

Composition : It contains Sn = 66% and Pb = 34%.

Properties :

(i) It melts at a constant temperature of 183°C without passing through a pasty region.

Uses :

(i) It is used for joining articles of tin in tin smith's work where penetration into small opening is often required.

(2) Wood's metal :

Composition : It contains Bi = 50%, Pb = 25%, Sn = 12.5% and Cd = 12.5%.

Properties :

(i) It is a low melting alloy which is readily fusible (m.p. 70°C).

Uses :

(i) It is used for making fire-alarms and automatic sprinklers.

(ii) It is used for making safety plug for cookers, milk pot etc.

(iii) It is used as a soft solder for joining two metallic parts.

(iv) It is used as castings for dental works.

1.6 NUMERICALS BASED ON COMPOSITION, DENSITY AND WEIGHT OF AN ALLOY

Problem 1: Calculate the composition, in weight percent, of an alloy that contains 210.0 kg titanium, 14.5 kg aluminum, and 15 kg vanadium.

Solution:

Total weight of the Alloy

= weight of titanium + weight of aluminum + weight of vanadium

= 210.0 kg (Ti) + 14.5 kg (Al) + 15 kg (V)

= 239.5 kg

Weight percent (Ti) = (weight of titanium/total weight) × 100
= (210.0/239.5) × 100
= 87.6 %

Weight percent (Al) = (weight of aluminum/total weight) × 100
= (14.5/239.5) × 100
= 6.05 %

Weight percent (V) = (weight of vanadium/total weight) × 100
= (15/239.5) × 100
= 6.26 %

Thus,

Composition of the alloy is 87.6% titanium, 6.05% aluminum, 6.26% vanadium

Problem 2: An alloy is made up of two metals - A (density of 0.90 g/cm^3) and B (density of 7.5 g/cm^3) given that A has mass of 25g in alloy and B has mass of 35g, what is density of the alloy?

$\rho = \frac{M}{V} \therefore V = \frac{M}{\rho}$

Solution:

Volume of A = Mass of A/Density of A = 25 g / 0.90 g/cm^3 = 27.78 cm^3

Volume of B = Mass of B/Density of B = 35 g / 7.5 g/cm^3 = 4.67 cm^3

Total volume of the Alloy = Volume of A + Volume of B = 27.78 cm^3 + 4.67 cm^3 = 32.45 cm^3

Mass of alloy = Mass of A + Mass of B = 25 g + 35 g = 60 g

Density of alloy = Mass of Alloy/Volume of Alloy = 60 g / 32.45 cm^3

Density of alloy = 1.85 g/cm^3

Thus,

Density of the alloy = 1.85 g/cm^3

Problem 3: Calculate the composition, in weight percent, of an alloy that contains 110 kg of iron, 0.5 kg of carbon, and 1.5 kg of chromium.

Solution:

Total weight of the Alloy
= weight of iron + weight of carbon + weight of chromium
= 110.0 kg (Fe) + 0.5 kg (C) + 1.5 kg (Cr)
= 112 kg

Weight percent (Fe) = (weight of iron/total weight) × 100
= (110/112) × 100
= 98.21 %

Weight percent (C) = (weight of carbon/total weight) × 100
= (0.5/112) × 100
= 0.45 %

Weight percent (Cr) = (weight of chromium/total weight) × 100
= (1.5/112) × 100
= 1.34 %

Thus,

Composition of the alloy is 98.21% iron, 0.45% carbon, 1.34% chromium

1.7 REVIEW QUESTIONS

1. Define an alloy. Give classification of alloys.

Ans. Refer Section 1.1 and 1.2.

2. Mention the composition and uses of German silver.

Ans. Refer Section 1.5.2.

3. What is plain carbon steel and how they are classified?

Ans. Refer Section 1.3.1 and 1.3.3.

4. Write the properties, uses and composition of (i) Gun metal, (ii) Nickel bronze.

Ans. Refer Section 1.5.2.

5. Write note on (i) heat resisting steel, (ii) corrosion resistant steel.

Ans. Refer Section 1.4.3.

6. What is the effect of following alloying elements on the properties of steels?
(i) Nickel, (ii) Chromium, (iii) Molibdenum, (iv) Cobalt

Ans. Refer Section 1.4.2.

7. Give the compositions, properties and uses of Wood's metal and Tinman's solders.

Ans. Refer Section 1.5.3.

8. Differentiate between brass and bronze.

Ans. Refer Section 1.5.2.

9. Give the compositions, properties and uses of Duralumin and Magnelumin.

Ans. Refer Section 1.5.1.

10. Give the compositions, properties and uses of Dutch Metal.

Ans. Refer Section 1.5.2.

11. Calculate the composition, in weight percent, of an alloy that contains 180.0 kg of A, 18 kg of B, and 25 kg of C.

Ans. A is 80.71%, B is 8.07%, C is 11.21%.

12. An alloy is made up of two metals - A (density of 1.25 g/cm^3) and B (density of 9.0 g/cm^3) given that A has mass of 30g in alloy and B has mass of 45g, what is density of the alloy?

Ans: Density of the alloy = 2.59 g/cm^3.

1.8 UNIVERSITY QUESTIONS

May 2008

1. Write composition, properties and uses of Duralumin. (3 M)

Ans. Refer Section 1.5.1.

2. Write composition and uses of Wood's metals. (2 M)

Ans. Refer Section 1.5.3.

May 2009

1. Give the composition, properties and uses of gun metal. (3 M)

Ans. Refer Section 1.5.2.

Dec. 2009

1. Give composition, properties and uses of gun metal. (3 M)

Ans. Refer Section 1.5.2.

2. Write note on magnelumin. (5 M)

Ans. Refer Section 1.5.1.

May 2010

1. Give composition, properties and uses of Wood's metal and magnalumin. (6 M)

Ans. Refer Section 1.5.3 and 1.5.1.

Dec. 2010

1. Give the composition, properties and uses of German silver. (3 M)

Ans. Refer Section 1.5.2.

May 2011

1. Give composition and uses of Duralumin. (3M)

Ans. Refer Section 1.5.1.

2. Define an alloy. (5M)

Ans. Refer Section 1.1.

3. Distinguish between brass and bronze. (5M)

Ans. Refer Section 1.5.2.

Dec. 2011

1. Give composition, properties and uses of Tinman's solders. (3M)

Ans. Refer Section 1.5.3.

May 2012

1. Give the composition and uses of duralumin. (3M)

Ans. Refer Section 1.5.1.

Dec. 2012

1. Give the composition, properties and uses of gun metal. (3M)

Ans. Refer Section 1.5.2.

2. Explain the effect of the following alloying elements on steel. (4M)
   (a) W (b) Mo (c) Ni (d) Cr.

Ans. Refer Section 1.4.2.

May 2013

1. Give the composition, properties and uses of German silver. (3M)

Ans. Refer Section 1.5.2.

2. Distinguish between brass and bronze. (5M)

Ans. Refer Section 1.5.2.

3. Explain the effect of the following alloying elements on steel. (5M)
   (a) W (b) Mo (c) Ni (d) Cr (e) Co.

Ans. Refer Section 1.4.2.

Dec. 2013

1. Give the composition, properties and uses of Wood's Metal. (3M)

Ans. Refer Section 1.5.3.

2. What are alloy steels? Explain the effect of the following alloying elements on steel. (6M)

   (a) W (b) Ni (c) Cr (d) Co.

Ans. Refer Section 1.4 and 1.4.2.

May 2014

1. Give the composition, properties and uses of Wood's Metal. (3M)

Ans. Refer Section 1.5.3.

2. What are the drawbacks of plain carbon steel? Explain the effect of the following alloying elements on steel. (6M)

   (a) W (b) Ni (c) Cr (d) Co.

Ans. Refer Section 1.3.4 and 1.4.2.

Dec. 2014

1. Give the composition, properties and uses of Duralumin. (3M)

Ans. Refer Section 1.5.1.

2. How are plain carbon steels classified based on carbon content? What are the drawbacks of plain carbon steel? (5M)

Ans. Refer Section 1.3.1 and 1.3.2.

3. What are alloy steels? Explain the effect of the following alloying elements on steel. (6M)

   (a) W (b) Ni (c) Cr (d) Co.

Ans. Refer Section 1.4 and 1.4.2.

May 2015

1. Give the composition, properties and uses of Wood's metal. (3M)

Ans. Refer Section 1.5.3.

2. What are alloys? (5M)

Ans. Refer Section 1.1.

3. Explain the effect of the following alloying elements on alloying. (5M)

   (a) C (b) Mo (c) Ni (d) Cr (e) Co.

Ans. Refer Section 1.4.2.

December 2015

1. Give the composition, properties and uses of German silver. (3M)

Ans. Refer Section 1.5.2.

2. Distinguish between brass and bronze. (5M)

Ans. Refer Section 1.5.2.

3. How are plain carbon steels classified based on carbon content? What are the drawbacks of plain carbon steels? (5M)

Ans. Refer Section 1.3.1 and 1.3.2.

May 2016

1. What are plain carbon steels? Mention any four drawbacks of plain carbon steel. (3M)

Ans. Refer Section 1.3.1 and 1.3.2.

2. List composition, properties and uses of the following alloys. (6M)

   (a) Duralumin, (b) Gun Metal.

Ans. Refer Section 1.5.1 and 1.5.2.

December 2016

1. Give the composition, properties and uses of Duralumin. (3M)

Ans. Refer Section 1.5.1.

CHAPTER 2

CERAMICS

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- 2.1.2 Properties of Ceramics
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2.5 Review Questions

2.1 CERAMICS

Ceramics are among the oldest materials known to man and have evolved from simple clay artifacts to high-performance materials of complexity. The term "ceramic"

finds its etymology in the Greek word "keramos", meaning "pottery" or "burnt stuff." Ceramics constitute an enormous category of inorganic, non-metallic materials formed through heat followed by cooling. Their history covers a wide spectrum of ancient artifacts, state-of-the-art technology, and a range of industrial applications. The study of ceramics combines the fields of physics, chemistry, and materials science in engineering materials to have defined properties for a given application.

Ceramics is an essential class of materials, bridging the gap between ancient craftsmanship and modern engineering. Progress in ceramic science promises to open up new avenues for its versatile applicability, healthcare needs, and technological innovations.

2.1.1 Definition and Types of Ceramics

Ceramics are defined as inorganic, non-metallic solids that are made by subjecting a material to high temperatures and often subsequent cooling. They are usually a chemical bond between metallic and non-metallic elements such as silicon carbide (SiC), aluminium oxide (Al_2O_3), and silicon nitride (Si_3N_4). Unlike metals, ceramics have crystalline or partially crystalline structures, though some are amorphous like glasses. Their properties are derived from the atomic bonding nature, which is mainly covalent and ionic, which provides mechanical, thermal, and chemical strength.

Types of Ceramics

Ceramics can broadly be classified into traditional and advanced ceramics:

1. **Traditional Ceramics**
   a) **Clay-Based Ceramics:** Examples are pottery, bricks, tiles, and porcelain. It is made mostly out of natural raw materials; clay, feldspar, and quartz.
   b) **Refractory Ceramics:** High-temperature materials applied in furnaces, kilns, and reactors.
   c) **Cement and Concrete:** Hydraulic binders, which form after clinkers get hydrated.
2. **Advanced Ceramics**
   a) **Structural Ceramics:** These are silicon carbide ~~and zirconium oxide~~ that are used in the aerospace, automotive, and defence sectors due to their durability and strength.
   b) **Functional Ceramics:** Piezoelectric, ferroelectric, and magnetic ceramics used in sensors, actuators, and electronics.

c) **Bio-ceramics:** Compositions like hydroxyapatite used for medical application in bone grafts and dental implants.

d) **Glass Ceramics:** A combination of glass and crystalline ceramics which have better thermal and mechanical properties.

2.1.2 Properties of Ceramics

The properties of ceramics are attributed to atomic and microstructural arrangements.

1. Mechanical Properties

High Hardness and Strength: Ceramics such as alumina show extremely high hardness, so they are used in the applications of cutting tools and abrasives.

Brittleness: Ceramics are brittle due to low plastic deformation capabilities; therefore, they can fracture under tensile stress.

2. Thermal Properties

High Melting Point: Ceramics can tolerate the extreme temperatures; therefore, they are crucial in the thermal insulation and high temperature processing.

Low Thermal Conductivity: Zirconia is one material that is a good thermal insulator.

Thermal Shock Resistance: High-performance ceramics do not crack due to thermal shocks.

3. Electrical Properties

Insulating Property: Alumina, for instance, is an excellent electrical insulator.

Semiconducting and Superconducting Property: Barium titanate is a material that has tailored electrical properties for electronics.

4. Chemical Properties

Corrosion Resistance: Ceramics resist degradation by acids, alkalis, and oxidizing agents.

Inertness: Chemical stability of ceramics makes them suitable for medical implants and food-grade applications.

2.1.3 Applications of Ceramics

The wide range of applications of ceramics is due to their versatile properties:

1. Industrial Applications

- Cutting tools, abrasives, and wear-resistant coatings.
- Engine, turbine, and bearing components.
- Furnace and kiln refractory linings.

2. **Electronics and Telecommunications**

- Dielectric materials in capacitors and substrates for microelectronics.
- Piezoelectric ceramics in transducers and actuators.
- Optical fibres and laser components.

3. **Medical Applications**

- Bio-ceramics for joint replacements, bone grafts, and dental prostheses.
- Materials for drug delivery systems and bioactive scaffolds.

4. **Environmental and Energy Applications**

- Catalysts and filters in pollution control.
- Solid oxide fuel cells for clean energy generation.
- Insulating materials in energy-efficient buildings.

2.2 GLASS

Glass is a mixture of number of silicates and hence no definite chemical formula can be assigned to it. It has no definite chemical composition. It is represented as $xM_2O.yM'O.6SiO_2$, where M is a monovalent alkali metal like Na, K etc.; M' is the bivalent metal like Ca, Zn, Pb etc. and x and y are whole numbers. The ordinary glass may be represented as $Na_2O.CaO.6SiO_2$.

2.2.1 Definition and Properties of Glass

Definition: Glass is an amorphous, hard, rigid, brittle, transparent, super-cooled liquid of infinite viscosity. It is obtained by fusing a mixture of a number of metallic silicate, most commonly of Ca, Na, K and Pb.

Properties of Glass:

1. It is amorphous, brittle, light with no definite melting point.
2. It can absorb, reflect or transmit light and can take high polish.
3. It is a good electrical insulator.
4. It is affected by alkalis, but not affected by air, water, acids or chemical reagents except HF.
5. It can be formed into articles, even of intricate shapes.
6. It softens on heating.
7. It has high compressive strength as it doesn't have crystal structure and hence there is no slippage between the planes.

2.2.2 Types of Glass

Some types of commercial glasses are as follows:

1. **Soda-lime or Soft glass:** Their composition is $Na_2O.CaO.6SiO_2$. The raw materials used are calcium carbonate, silica and soda ash. The are low in cost, resistant to devitrification and resistant to water. They melt easily, and attacked by common reagents like acids.

   Uses: They are used as window glasses, plate-glasses, bottles, jars, electric bulbs, building blocks and cheaper tablewares.

2. **Potash-lime or Hard glass:** Their composition is $K_2O.CaO.6SiO_2$. They have high melting point and fuse with difficulty. They are less acted upon by acids, alkalis and other solvents than ordinary glasses.

   Uses: They are used for chemical apparatus, combustion tubes which are generally used in heating operations.

3. **Borosilicate Glass or Pyrex glass or Jena glass:** It is a mixture of sodium aluminium borosilicates. It contains boron trioxide. It is rich in silica, but poor in alkali and alumina. It is the most common of the hard commercial glass. It has low thermal coefficient of expansion, very high softening point and excellent resistance to s hock and chemicals.

   Uses: They are used for pipelines for corrosive liquids, for laboratory glassware, kitchen wares, television tubes, electrical insulators etc.

4. **Lead Glass or Flint glass:** Their approximate composition is $K_2O.PbO.6SiO_2$. It is made by using lead oxide instead of calcium oxide for fusing together with silica. It has a lower softening temperature than soda glass and a higher refractive index. It is bright and lustrous. It has high specific gravity (3 to 3.3) and excellent electrical properties.

   Uses: They are used for high quality tableware, optical purposes, neon sign tubing, cathode-ray tubes, electrical insulators and in art objects. High lead content glasses are used for extra-dense optical glasses for windows and shields which are used to protect personnel from X-rays and gamma-rays.

5. **Vitreosil or 99.5% Silica glass:** It is produced by heating pure sand to it's melting point (1750°C). The glass so produced, can not be shaped as it has a very high viscosity at the working temperature. It's softening temperature is about 1659°C and it's thermal expansion is the lowest. After heating for long period of time, above it's melting point, it finally becomes transparent and is known as 'clear silica glass'. This glass has considerable light transmission properties.

   Uses: It is used for chemical plants, chemical laboratory wares, electrical insulating materials in electrical heaters, furnaces etc.

6. **Safety glass:** It is made by introducing thin layers of vinyl plastic between two or three flat sheets of glass, and it is subjected to slight pressure and heat till the glass and plastic layers merge into one another like a sandwich. Once cooled the glass becomes quite tough. When the toughened glass breaks, it doesn't fly into pieces, since the inner plastic layer holds back the broken pieces of the glass.

   Uses: It is used as wind shield in automobile and aeroplane industry. It is also used in building construction.

7. **Optical or Crookes glass:** It contains lead silicate and phosphorous together with small quantities of *cerium oxide*. The latter is capable of absorbing ultra-violet light which is injurious to eyes. This glass is made by very careful manufacturing process involving heating the molten mass for a prolonged period of time. The optical glasses are relatively soft and have low melting points. Their chemical resistance and durability are much lower than the normal glass.

   Uses: They are used for making optical lenses.

8. **Toughened glass:** It is a type of glass which is made by controlled thermal or chemical treatments to increase it's strength compared to the ordinary glass. It is tempered in such a way that the outer layer of the article is in a state of compression and the inner layer is in the state of tension. Such a glass is more elastic, and can withstand mechanical and thermal shocks. When broken, it shatters into small granular chunks, and does not fly into large jagged shreds like an ordinary glass.

   Uses: It is used for window shields of fast moving vehicles, window shields of furnaces and automatic opening doors.

9. **Laminated glass:** It is made by pressing together two or more sheets of glass with one or more alternating layers of bonding materials, plastic resin, asphalt or synthetic rubber. It is shatter proof and shock proof. A bullet-resistant laminated glass is obtained by pressing together several layers of glass with vinyl resins in alternate layers. Thickness of such glass varies from 12.7 mm to 76.5 mm.

   Uses: It is used as safety glass in aircrafts, automobiles, helicopters, submarines etc. Bullet-resistant laminated glass is used in making automobiles wind screens, looking windows etc.

10. **Glass Wool or Fibre glass:** Glass wool is a fibrous wool-like material composed of intermingled fine threads or filaments of glass. Glass filaments are obtained by forcing the molten glass through small orifices of average diameter 0.005 mm to 0.007 mm. The thread of glass so obtained is thrown over a rapidly revolving drum. This is how the glass is drowned into fine fibres of wool or silk. It is

noncombustible, fire-proof, heat-proof with low density and thermal conductivity. It resists action of most of chemicals and does not absorb moisture. It's tensile strength is about eight times more than steel.

Uses: The glass wool is woven into decorative textiles which are fire-proof. Being resistant to chemicals, it is used for filtration of corrosive liquids like acids. It is used for electrical and sound insulation.

2.3 ABRASIVES

Abrasive is a substance that can be used for grind away the surface of another substance. It can also be used for cutting, surfacing or finishing another material. Due these properties, the abrasives find a number of applications in day-to-day life and engineering industry. We get to see the abrasives in the knife sharpening grinder, in the tiny abrasive tools used by the dentist to smooth-down the fillings and clean the teeth, and engineering cutting tools are sharpened using abrasives.

2.3.1 Definition and Characteristics of Abrasives

Abrasives: These are the substances characterized by their hardness and are used to wear down sifter substances by cutting, grinding or polishing.

Characteristics of Abrasives:

1. It should have high abrasive power. Abrasive power is the capacity of a particular abrasive to rubdown other objects which depends upon the hardness, toughness and refractoriness of the abrasive.
2. It should be very hard. Hardness is the capacity of a substance to scratch or make marks on other substances. The harder the abrasive better the capacity it has to scratch the other objects. Hardness is measured roughly on Mohs scale.
3. It should be tough and resistant to mechanical shock. Toughness measures the resistance of the material to shattering (opposite of brittleness).
4. It should possess high refractoriness. Refractoriness is the resistance of an abrasive to breaking of it's grain and softening with the rise in temperature.
5. It should not be affected by the frictional heat.

2.3.2 Classification of Abrasives

Based on availability, abrasives may be classified as natural abrasives and artificial abrasives.

(A) Natural Abrasives:

1. **Diamond** – It is the most known abrasive. It is the hardest material with high scratching power. It is chemically inactive. They are not attacked by acids, and fused potassium chlorate. The black diamond is called the cabanado which has no value for jewelry. Faulty diamonds which are off color are called borts.

   Uses: Carbanados and borts find their applications in drill points, saw teeth for cutting rocks, polishing gems and for dressing grinding wheels.

2. **Corundum** – It is a crystalline form of aluminium oxide (Al_2O_3). In terms of hardness, it is next to diamond.

   Uses: It is used in the manufacture of abrasive wheels used in the metal industry. It is used as abrasive for grinding glasses, gems and lenses.

3. **Garnets** – They are trisilicates of alumina, magnesia and ferrous oxide. Their hardness is between 6 to 7.5 on Mohs scale. Due to limited hardness, they can't be used to grind steel and iron.

   Uses: They are glued to paper or cloth and are used for finishing hard woods. They are used for glass grinding and polishing metals.

4. **Quartz** – It is composed of silica (SiO_2). It is as hard as garnet. Grinding and other sharpening stones are cut from sand stones.

   Uses: It is used for grinding floor, pigments, ores etc.

5. **Emery** – It is dark gray to black in color. It is fine grained, opaque massive mineral. It is an aggregate of 55 to 75% crystalline alumina, 20 to 40% magnetite (Fe_3O_4) and 12% other minerals. It's hardness is 8 on Mohs scale. The grinding power of emery depends on the proportion of alumina it contains and on the effect of the other ingredients.

   Uses: It is used as tips of bits of cutting and drilling tools.

(B) Artificial Abrasives:

1. **Silicon Carbide or Carborundum (SiC)** – It is blueish-black crystalline artificial mineral. It is very hard (Mohs scale = 9.3). It's hardness is between that of Corundum and Diamond. It is chemically unreactive. It can withstand high temperature without damage. It is brittle (not tough). It is made by subjecting a mixture of silica and carbon to high temperature of 1650 to 2200°C in an electric furnace.

$$SiO_2 + 3C \rightarrow SiC + 2CO$$

Uses: It is used in an abrasive paper, cutting wheels and clothes. It is used for grinding low tensile strength materials like cast iron, brass, bronze, porcelain. It is used for grinding optical lenses.

2. **Alundum (Al_2O_3)** – It is fused Aluminium Oxide made from impure bauxite or red bauxite. It is not as hard as carborundum. It is less brittle and tough. It is prepared by subjecting a mixture of calcined bauxite, coke and iron to high temperature (about 4000°C) in an electric arc furnace. The titanium, iron and silica impurities settle at the bottom of the furnace. The hard crystalline alumina is separated after solidification.

   Uses: It is used for grinding hard steels and other high tensile strength materials. It is used for finishing wood works on an abrasive paper and cloth.

3. **Boron Carbide (B_4C)** – It is also known as norbide. It is inert. It is one of the hardest artificial abrasive (Mohs scale = 9). It is manufactured by heating boron oxide with coke in an electric furnace to the temperature 2700°C.

$$2B_2O_3 + 7C \rightarrow B_4C + 6CO$$

   Uses: It is used for making grinding dies. It is used for cutting and sharpening hard high speed tools.

2.4 OPTICAL FIBRES

Optical fibre is the flexible, transparent fibre made of high quality glass or plastic that transmits light between two ends of the fibre. It works on total internal reflection principle by transmitting light with minimal loss for a long distance. Signal transmission through a metallic wire conductor is by electrons (i.e. electronic), whereas in case of optical fibres, it is by photons (i.e. photonic). The communication field has experienced a revolution due to the optical fibre technology. These fibres are very effective and versatile in various communication systems, medical devices, and industries.

2.4.1 Definition

Optical fibres are the fibres of about hair diameter made from high purity, negligible loss, very low dispersion glass. It is used as medium for telecommunication by transmission of high frequency pulses of light.

2.4.2 Components of Optical Transmission System

An optical transmission system essentially consists of the following parts:

1. Optical Transmitter

The information in the electronic form is first digitized into bits in the encoder. It is further converted into an optical signal in the electrical-to-optical converter. The converter is a semiconductor laser which emits monochromatic and coherent light.

2. Transmission Medium

Optical fibres act as the transmission medium. It guides the light pulses over long distances without any signal power loss and pulse distortion.

The optical fibre consists of three layers:

Core: Central region made of highly pure silica, where light propagation occurs. It is the innermost light guiding region.

Cladding: It covers the core and ensures complete internal reflection due to its lower refractive index.

Buffer Coating: It is the outermost protective covering which offers mechanical strength to the optical fibre and prevents mechanical damage and other environmental influences.

3. Optical Receiver

It converts the light signal back to an electrical signal.

It contains a photodetector, a photodiode, amplifiers, and signal processors. The photodiode converts the light signal into an electrical signal. The amplifiers amplify the signal strength without converting it back to electrical form.

In addition to the above main components, there are also Regenerators and Wavelength Division Multiplexers in the optical transmission systems. The Regenerator reconstructs and amplifies the weakened signals to enable long-distance communication. The Wavelength Division Multiplexer (WDM) combines and separates different light signals of various wavelengths for efficient utilization of fibre capacity.

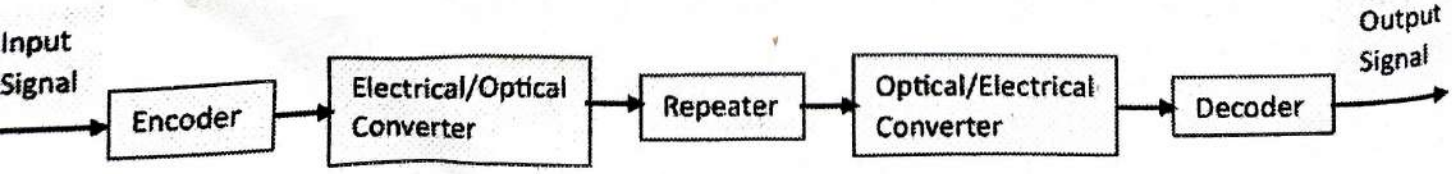


Fig. 2.1 : Components of an Optical Fibre Communication System

2.4.3 Advantages of Optical Fibre Communication

1. **High Bandwidth**

   Optical fibres have unmatched data transmission capacity compared to copper cables, thereby making them suitable for high speed internet and communication.

2. **Low Attenuation and Long-Distance Transmission**

   Signal loss in optical fibres is minimal, allowing efficient data transmission over long distances without requiring frequent repeaters. This feature has become major advantage in optical fibre communication.

3. **Immunity to Electromagnetic Interference**

   Unlike metallic cables, optical fibres are unaffected by electromagnetic interference, ensuring signal integrity in electrically noisy environments.

4. **Enhanced Security**

   The optical fibres are difficult to tap into since the light from optical fibre does not radiate significantly, providing superior security for data transmission.

5. **Compact and Lightweight**

   The optical fibres have a very small diameter and are light in weight, thus making them easier to install and maintain than traditional cabling systems.

6. **Cost-Effective Over Time**

   Though the installation costs may be higher in the case of optical fibres in the initial stages, the low maintenance and operational costs result in huge savings over time.

7. **Ruggedness and Flexibility**

   The optical fibres are superior in terms of storage, transportation, handling and installation compared to conventional copper cables.

2.4.4 Applications of Optical Fibres

1. **Telecommunications**

   Optical fibres are the backbone of internet infrastructure.

   They enable high-speed data transfer for mobile networks, broadband services, and global communication systems.

2. Medical Applications

Optical fibres have large number of applications in medical fields. The inaccessible parts of the human body can be studied using illumination with optical fibres. They are used in endoscopy to illuminate and visualize internal organs. They can be employed to attach a detached retina or rectify other eye defects using lasers. It plays an important role in the minimally invasive surgeries. The laser angioplasty has replaced ballon angioplasty and open by-pass surgeries.

3. Industrial and Military Use

Optical fibres are finding extensive applications in the industry and military operations. The conventional coper cables are much difficult to transport through an aircraft or a ship due to their weight. But in case of optic fibres the weight of cables is enormously reduced, and the communication network is greatly improved. They are also utilized in the sensors to monitor temperature, pressure, and strain in harsh environments. Since higher signal secrecy is also maintained in the optical fibres, they employed in secure communication networks for military operations.

The optical fibre technology is extensively used in the guided missile technology in current warfare.

4. Broadcasting and Cable TV

Optical fibres deliver high-definition audio and video signals with minimal loss and interference.

5. Lighting and Decorative Purposes

Optical fibres are used in architectural lighting, illumination of remote areas, and artistic installations.

6. Scientific Research

Optical fibres are integral to advanced fields like spectroscopy and interferometry. It plays a crucial role in designing precise instrumentation for astronomy and particle physics.

7. Automotive and Aerospace Industries

Optical fibres facilitate reliable communication and control systems within vehicles and aircraft. It lowers weight while maintaining high performance.

2.5 REVIEW QUESTIONS

1. Write notes on,
   (a) Vitreosil Glass, (b) Safety Glass, (c) Optical Glass, (d) Toughened Glass.
   Ans. Refer Section 2.2.2.
2. Explain any three types of glasses.
   Ans. Refer Section 2.2.2.
3. Define glass and explain Soda-lime glass.
   Ans. Refer Section 2.2.1 and 2.2.2.
4. Define glass and write informative note on potash-lime glass.
   Ans. Refer Section 2.2.1 and 2.2.2.
5. Give any five properties of glass.
   Ans. Refer Section 2.2.1.
6. Write brief notes on,
   (a) Borosilicate glass, (b) Lead glass, (c) Laminated glass, (d) Glass wool.
   Ans. Refer Section 2.2.2.
7. Define abrasive and explain diamond.
   Ans. Refer Section 2.3.1 and 2.3.2.
8. Give the classification of the abrasives with examples.
   Ans. Refer Section 2.3.2.
9. Define abrasive and explain Corundum.
   Ans. Refer Section 2.3.1 and 2.3.2.
10. Write informative note on,
    (a) Garnets, (b) Quartz, (c) Emery
    Ans. Refer Section 2.3.2.
11. Give the characteristics of abrasives.
    Ans. Refer Section 2.3.1.
12. Explain in brief, (a) Silicon Carbide, (b) Alundum, (c) Bron Carbide
    Ans. Refer Section 2.3.2.
13. Define Ceramics.
    Ans. Refer Section 2.1.1.
14. Explain the types of Ceramics
    Ans. Refer Section 2.1.1.

15. Explain the properties of Ceramics.

Ans. Refer Section 2.1.2.

16. Write an informative note on applications of Ceramics.

Ans. Refer Section 2.1.3.

17. What are optical fibres?

Ans. Refer Section 2.4 and 2.4.1.

18. Write a short note on components of optical transmission system.

Ans. Refer Section 2.4.2.

19. Give the advantages of optical fibre communication.

Ans. Refer Section 2.4.3.

20. Explain the applications of optical fibres.

Ans. Refer Section 2.4.4.

CHAPTER 3

COMPOSITES

CONTENTS

3.1 Introduction
3.2 Characteristic Properties of Composite Materials
3.3 Classification
3.4 Particle Reinforced Composites
3.5 Fibre Reinforced Composite
3.6 Structural Composites
3.7 Applications of Composite Material
3.8 Bio Composites
3.8.1 Classification of Bio-Composites
3.8.2 Applications of Bio-Composites
3.9 Review Questions
3.10 University Questions

3.1 INTRODUCTION

The materials available to the engineer include timber, stone, cement, metals, textiles, ceramics and plastics. Our modern technologies, many a times demand materials with unusual and extraordinary combinations of properties that cannot be provided by the conventional metal alloys, ceramics and polymeric materials. This ever-increasing demand for special materials having unusual combination of properties for use in our modern technologies is responsible for the development of composite materials.

A composite is a combination of two or more materials that has properties different from its constituents. Composites as a class of engineering material provide almost an unlimited potential for higher strength, stiffness and corrosion resistance over the pure material systems of metals, ceramics and polymers. They will probably be the 'steels' of the next century.

3.2 CHARACTERISTIC PROPERTIES OF COMPOSITE MATERIALS

The important characteristics of composite materials are as follows:

1. Higher specific strength and specific stiffness.
2. Lower specific gravity, electrical conductivity and thermal expansion.
3. Better toughness, impact and thermal shock resistance, creep and fatigue strength, corrosion and oxidation resistance.
4. Maintains strength even at high temperature.
5. Can be fabricated easily and economically.

3.3 CLASSIFICATION

One simple scheme for the classification of composite materials is shown in **Fig. 3.1**. It consists of three main divisions particle reinforced, fibre reinforced and structural composites.

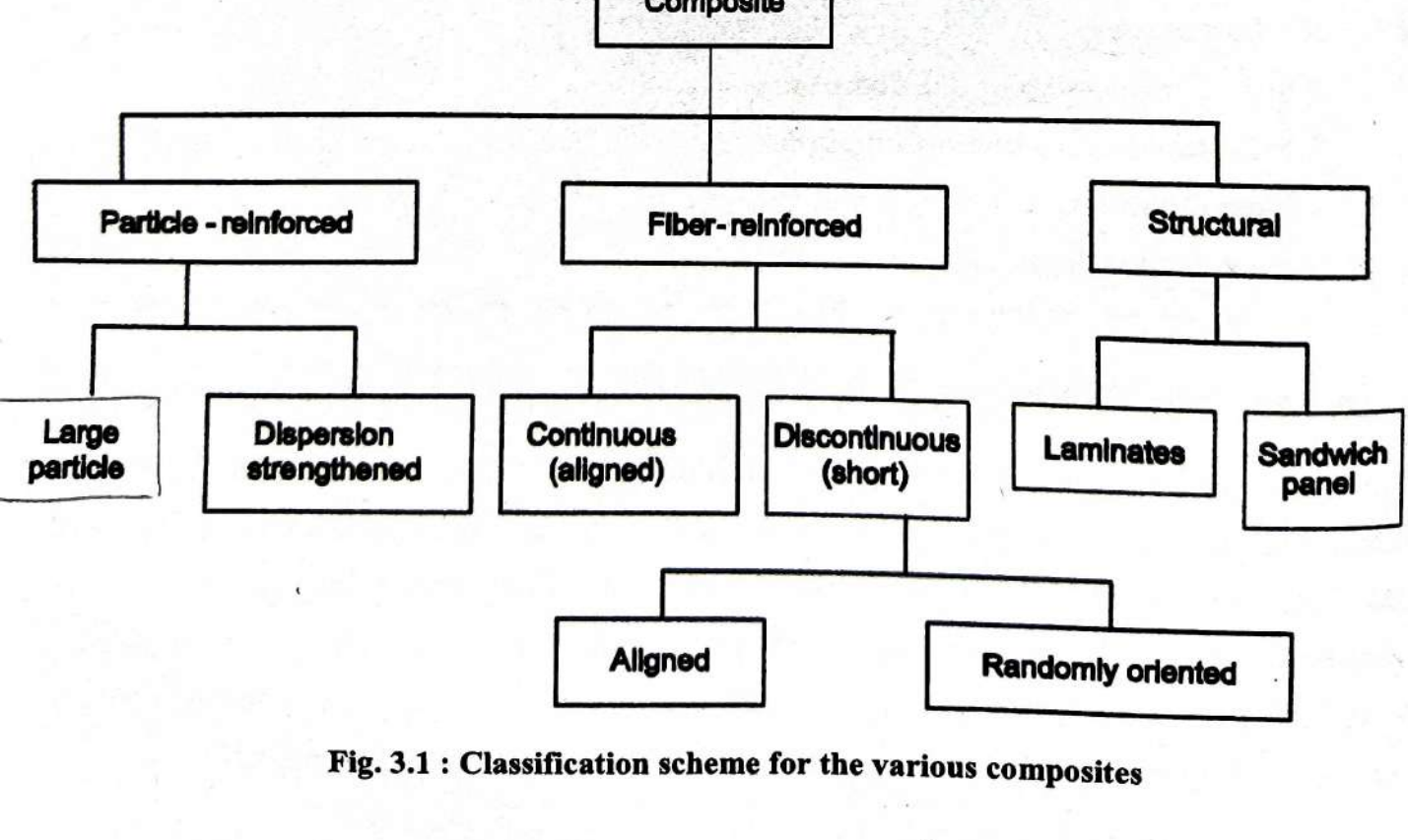


Fig. 3.1 : Classification scheme for the various composites

The dispersed phase for particle-reinforced composite is equiaxed (i.e. particle dimensions are approximately the same in all directions), for fibre-reinforced composites, the dispersed phase has the geometry of a fibre (i.e. a large length-to-diameter ratio). Structural composites are combinations of composites and homogeneous materials.

3.4 PARTICLE REINFORCED COMPOSITES

Particulate composites are made by dispersing particles of varying size and shape of one material in a matrix of another material. The operation may be carried out by adding particles to a liquid matrix material. It later solidifies (during age hardening) or may be pressed together (by the powder process).

Large particle and dispersion strengthened composites are the two sub-classifications of particle reinforced composites. The distinction between these is based upon reinforcement or strengthening mechanism.

Large Particle Composites : (1) This is main & primary constituents material that hold the reinforcement materials together.

The term 'large' is used to indicate that particle matrix interactions can not be treated on the atomic or molecular level. In most of these composites, the particulate phase is harder and stiffer than the matrix. The matrix is reinforced by hard particles of three-dimensional shape. Volume of the second phase particles is greater than 20 percent and the particle size is more than one micron. Therefore, particle reinforced composites would have greater volume fraction and larger particle size as compared to dispersion strengthened composites. These reinforcing particles help to restrain the movement of the matrix phase in the vicinity of each particle. The matrix transfers some of the applied stress to the particles which bear a fraction of the load. The degree of reinforcement or improvement of mechanical behavior depends on strong bonding at the matrix particle interface. (2) Matrix phase materials plays a crucial role in determining the overall properties and performance of composite materials

These particles can have quiet a variety of geometries, but they should be of approximately the same dimension in all directions. For effective reinforcement, the particles should be small and evenly distributed throughout the matrix.

Although these composites do not offer potential for high strengthening, their use has been more widespread than any other composite materials. Other than strength, they offer many improvements over elemental materials or alloys in many categories. Uses of these materials include powder metallurgy structural parts, cutting tools, drills, electrical contacts, magnets, radiation shielding, spark machining electrodes and rocket nozzles.

Some polymeric materials to which filers have been added are really large particle composites. The fillers modify the properties of the material. Another familiar large particle composite is concrete, which is composed of cement (the matrix) and sand and gravel (the particulate).

Some other examples of materials of this group are tungsten reinforced copper, iron-copper etc. which are prepared by powder metallurgy techniques.

Large particle composites are utilized with all three material types (metals, polymers and ceramics). The cermets are examples of ceramic metal composites. The most common cermet is the cemented carbide which has been commercially developed for the last ten years. Their introduction has revolutionized the cutting tool industry because of their properties such as high hardness and wear resistance, high strength, toughness and resistance to deformation at elevated temperatures.

Cemented carbide (also known as sintered hard metal) are composed of carbide phase dispersed in a metallic matrix. Depending upon the carbide phase and the matrix, presently available cemented carbides can be divided into two groups. Firstly, tungsten carbide and cobalt alloys and secondly complex carbides in cobalt and nickel matrices. Commonly used cemented carbide alloys contain 70 to 98 percent tungsten carbide in a cobalt matrix. The cutting efficiency of these carbides can be further improved by addition of titanium and tantalum carbides.

The hard carbide particles provide the cutting surface but being extremely brittle, are not themselves capable of withstanding the cutting stresses. Toughness is enhanced by their inclusion in the ductile metal matrix, which isolates the carbide particles from one another and prevents particle-to-particle crack propagation. Both matrix and particulate phase are quite refractory, to withstand the high temperatures generated by the cutting action on materials that are extremely hard. No single material could possibly provide the combination of properties possessed by a cermet.

Cemented carbides possess hardness of the order of 1100 to 1800 vickers and are primarily used for cutting of steels of all types at high speeds.

Elastomers and plastics are reinforced with various particulate materials. Use of modern rubbers would be restricted without reinforcing particulate materials such as carbon black which consists of very small and essentially spherical particles of carbon. They are produced by the combustion of natural gas or oil in an atmosphere that has only a limited air supply. Carbon black when added to vulcanized rubber enhances its tensile strength, toughness and tear and abrasion resistance. Automobile tyres contain on the order of 15-30 volume % of carbon black. For providing significant reinforcement, the particle size of carbon black must be small (with diameter between 20 to 50 nm) and evenly distributed throughout the rubber.

Concrete is a common large particle composite in which both matrix and dispersed phases are ceramic materials. Concrete implies a composite material consisting of an aggregate of particles that are bound together in a solid body by some type of binding medium that is a cement. The two most familiar concretes are those made with Portland

and asphaltic cements where the aggregate is gravel and sand. Asphaltic concrete is widely used primarily as a paving material. Portland cement concrete is employed as a structural building material. The strength of Portland cement concrete may be increased by additional reinforcement by means of steel rods, wires, bars or mesh embedded into fresh and uncured concrete.

The substance embedded in the matrix phase are known as D-P which surround & support it & combined effect of two phases result in the superior properties of the composites.

Dispersion Strengthened Composites : When the strength of a soft and ductile metal matrix (metals and metal alloys) is increased by the uniform dispersion of hard second phase particles, the resulting materials is called a dispersion reinforced composite. The hard second phase particles are generally oxides and carbides which are insoluble and incoherent with the matrix. Their diameter varies from 0.1 to 1.0 microns and is dispersed in a volume concentration of 1 to 15 percent.

In dispersion strengthened composites, the matrix is the major load bearing constituent. The fine dispersions act as a barrier to the motion of dislocations in the matrix. Their advantage is not so much to improve the yield strength or work hardening of the matrix, but their ability to maintain the yield strength increase and creep resistance increase over a wide temperature range. Some of the factors determining the effectiveness of dispersion are the interparticle separation, particle diameter and volume fraction of the particles. Typical dispersion strengthened composites are alumina particle reinforced aluminium (for example sintered aluminium product called SAP) and thoria dispersed nickel (TD Nickel).

Alumina reinforced aluminium composites are obtained by pulverization of aluminium metal to powder, oxidation (to a given degree) of this powder, and sintering of the oxidized powder with aluminium. These Al-Al_2O_3 composites, (For example SAP), have a structure that results in high temperature mechanical properties. A low density SAP contains varying amounts of aluminium oxide, generally between 7 and 14 percent).

The high temperature strength of nickel alloys may be enhanced significantly by the addition of about 3 volume % of thoria (ThO_2) as finely dispersed particles known as thoria dispersed (or TD) nickel.

3.5 FIBRE REINFORCED COMPOSITE

Technologically, the most important composite in which the dispersed phase is in the form of fibre. The high strength, high modulus fibres are incorporated in metal, ceramic and plastic materials. The fibres can be employed either in the form of continuous lengths, staples or whiskers. Such composites possess high specific strength (tensile

strength/specific gravity) and high specific modulus (elastic modulus/specific gravity) stiffness and lower overall density.

Composites of this group can achieve unique combination of properties such as high stiffness, high specific strength, elevated temperature strength, high fracture toughness etc. which are determined by the properties of the matrix and the reinforcing fibres.

A fibre-reinforced composite material consists of three main constituents, namely, matrix, fibres and the interface. The main purpose of the matrix is to transmit the load to the fibre which is the principal load bearing constituent. When uniform and continuous fibres are unidirectionally dispersed throughout the composite, then the composite strength will depend upon the strength, volume fraction, and orientation of the fibres. In addition, the composite properties will also depend upon the nature of the bonding, chemical activity, and diffusion between the matrix and the fibre.

Fibre reinforced composites are sub-classified by fibre length as shown in **Fig. 3.2.**

The mechanical characteristics of a fibre-reinforced composite depend on :

1) Nature and properties of both, fibres as well as matrix phase and their relative volume fraction.
2) On the degree to which an applied load is transmitted to the fibres by the matrix phase.
3) Critical fibre length is necessary for effective strengthening and stiffening of the composite material. This critical length 'l_c', is dependent on the fibre diameter 'd' and its ultimate strength 'σ^*_f', and on fibre matrix bond strength 'T_c'.

$$l_c = \frac{\sigma^*_f}{2T_c}$$

This critical length is on the order of 1 mm, which ranges between 20 and 150 times the fibre diameter. Fibres for which fibre length $l >> l_c$ (normally $l > 15\, l_c$) are termed continuous. For discontinuous fibres of lengths significantly less than l_c, the matrix deforms around the fibre such that there is virtually no stress transference and little reinforcement by the fibre.

4) The strength and other properties of fibre-reinforced composites mainly depend on the arrangement or orientation of the fibres relative to one another, the fibre concentration, and the distribution. Based on fibre orientation two extremes are possible (i) a parallel alignment of the longitudinal axis of the fibres in a single direction. (ii) a totally random alignment. Continuous fibres are normally aligned (Fig. 3.2 (a)) whereas discontinuous fibres may be aligned (Fig. 3.2 (b)), randomly oriented (Fig. 3.2 (c)) or partially oriented.

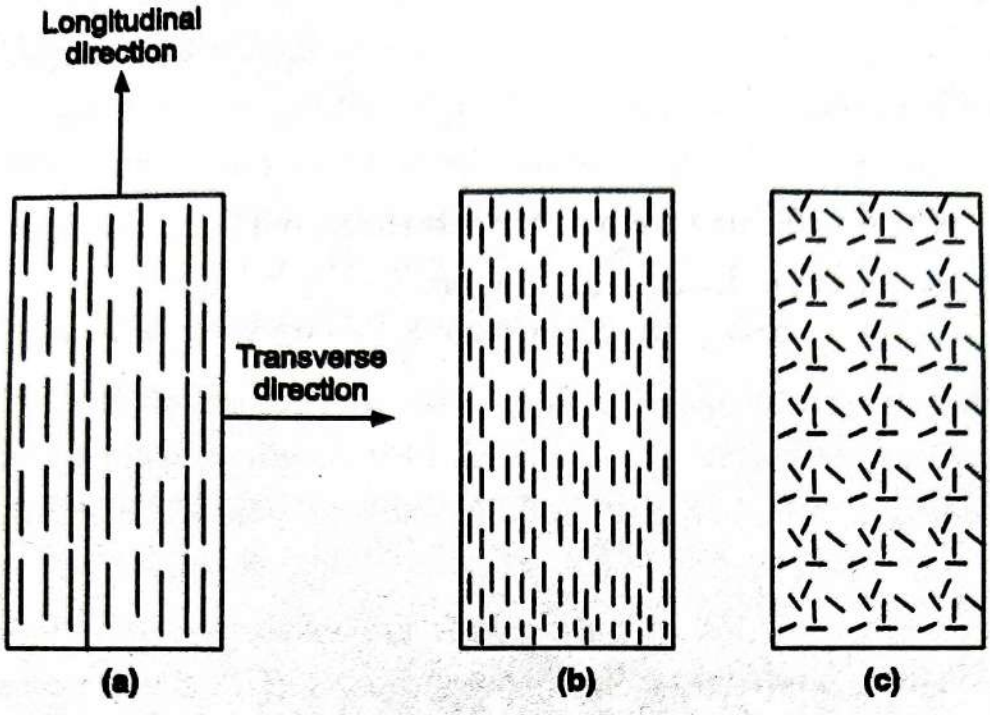


Fig. 3.2 : Schematic representation of fibre reinforced composites

i) **Continuous and Aligned Fibre Composites :** The properties of continuous and aligned composites are highly anisotropic, that is they depend on the direction in which they are measured. The maximum strength is achieved along the direction of fibre alignment (longitudinal). The fibre reinforcement being virtually non-existent in the transverse direction and hence fracture occurs at relatively low tensile stresses.

ii) **Discontinuous Fibre Composites :** There are two types of discontinuous fibre composites namely (a) Discontinuous and aligned fibre composites and (b) Discontinuous and randomly oriented fibre composites.

The discontinuous fibres have lower reinforcement efficiency than that for continuous fibres. The discontinuous and aligned fibre composites have greater application in the commercial market compared to continuous and aligned composites. The reinforcement is done with chopped glass fibres, carbon and aramid discontinuous fibres.

Some important types of Fibre reinforced composites are as follows :

1) **Fibre Glass Reinforced Composite :** GFRP composite is produced in the largest quantities. Fibre glass is a composite consisting of glass fibres either continuous or discontinuous contained within a polymer matrix. Glass is a very popular reinforcement material due to the following reasons :

i) It is readily available and has low cost of production by the commonly available manufacturing techniques.

ii) It is easily drawn into high strength fibres from the molten state.

iii) When the strong glass fibres are embedded in a phase matrix, it produces a composite having a very high specific strength.

iv) It shows chemical and corrosion resistivity when coupled with various plastics.

v) It has low co-efficient of thermal expansion and low dielectric constant.

vi) It has high dimensional stability and good tensile strength.

Fibre diameter normally ranges between 3 and 20 μm. Glass fibres are durable and are acid proof, water-proof and fire-proof. They neither shrink nor stretch. For glass reinforced plastics, the strength increases with fibre length. Tensile and impact strength, modulus of elasticity and dimensional stability increase with increase in glass content in GRP.

The surface characteristics of glass fibres are extremely important because even minute surface flaws can affect the tensile properties. Surface flaws are easily introduced by rubbing or abrading the surface with another hard material. Glass surfaces, if exposed to the normal atmosphere, generally have a weakened surface layer that interferes with bonding to the matrix.

Applications :

i) Fibre glass applications are found in automotive and marine bodies, plastic pipes.

ii) They are also used in storage containers and industrial floorings.

iii) It can be used for air filters to remove dust from the air, for preparing insulating materials against heat, sound and electricity.

iv) It is used as pipe insulation as well as insulation blankets.

v) It is used extensively in transportation industries to reduce vehicle weight and boost fuel efficiencies.

Limitations :

i) They are not very stiff and do not display the rigidity required for some applications. (For example, structural members of airplanes and bridges.)

ii) Most fibre glass materials are limited to service temperatures below 200°C; at higher temperatures most polymers begin to flow or to deteriorate.

2) **Carbon Fibre Reinforced Polymer Composite :** Carbon is a high performance fibre reinforcement material used in advanced (i.e. non-fibre glass) polymer matrix composites due to the following reasons :

i) Carbon fibres have highest specific modulus and specific strength of all reinforcing fibre materials.

ii) At high temperature, they retain their high tensile modulus and high strength at elevated temperature.

iii) At room temperature, they are unaffected by moisture, solvents, acids and bases.

iv) They exhibit different physical and mechanical characteristics allowing composites incorporated properties.

v) Relatively inexpensive and cost effective fibre and composite manufacturing processes have been developed.

Carbon fibres are not totally crystalline, but are composed of both graphite and non-crystalline regions. They are normally coated with a protective epoxy size which improves adhesion with the polymer matrix.

Applications :

i) They are being utilized in sports and recreational equipment (fishing rod, golf clubs).

ii) They are used in filament-wound rocket motor cases and pressure vessels.

iii) They are also used in aircraft industry in the form of structural components.

3) **Metal-Matrix Composites :** For metal-matrix composites (MMCs) the matrix is a ductile metal. These materials may be utilized at higher service temperatures than their base metal counterparts. The reinforcement may improve specific stiffness, specific strength, abrasion resistance, creep resistance, thermal conductivity, and dimensional stability. They are better than PMCs because of higher operating temperatures, non-flammability, and greater resistance to degradation by organic fluids.

The super-alloys as well as alloys of aluminium, magnesium, titanium and copper are employed as matrix material. The reinforcement may be in the form particulates, fibres and whiskers. Continuous fibre materials include carbon, silicon carbide, boron, aluminium oxide and the refractory metals.

The high temperature creep and rupture properties of some of the super-alloys (Ni and Co-based alloys) may be enhanced by fibre reinforcement using refractory metals such as tungsten. Excellent high temperature oxidation resistance and impact strength are also maintained. Designs incorporating these composites permit higher operating temperatures and better efficiencies for turbine engines.

4) **Hybrid Composites :** A relatively new fibre reinforced composite is the hybrid. They are obtained by using two or more different kinds of fibres in a single matrix having a better all-around combination of properties than composites containing only a single

fibre type. In the common system, both carbon and glass fibres are incorporated into a polymeric resin. The glass-carbon hybrid is stronger and tougher and has a higher impact resistance. They may be produce at a lower cost than either of the comparable all-carbon or all-glass reinforced plastics.

In number of ways, two different fibres may be combined which will ultimately affect the overall properties. For example, the fibres may all be aligned and intimately mixed with one another; or laminations may be constructed consisting of layers, each of which consists of a single fibre type.

When hybrid composites are stressed in tension, failure does not occur suddenly. For example, the carbon fibres are the first to fail, at which time the load is transferred to the glass fibres. Upon failure of the glass fibres the matrix phase must sustain the applied load.

Principal applications for hybrid composites are lightweight land, water and air transport structural components, sporting goods, and lightweight orthopedic components.

3.6 STRUCTURAL COMPOSITES

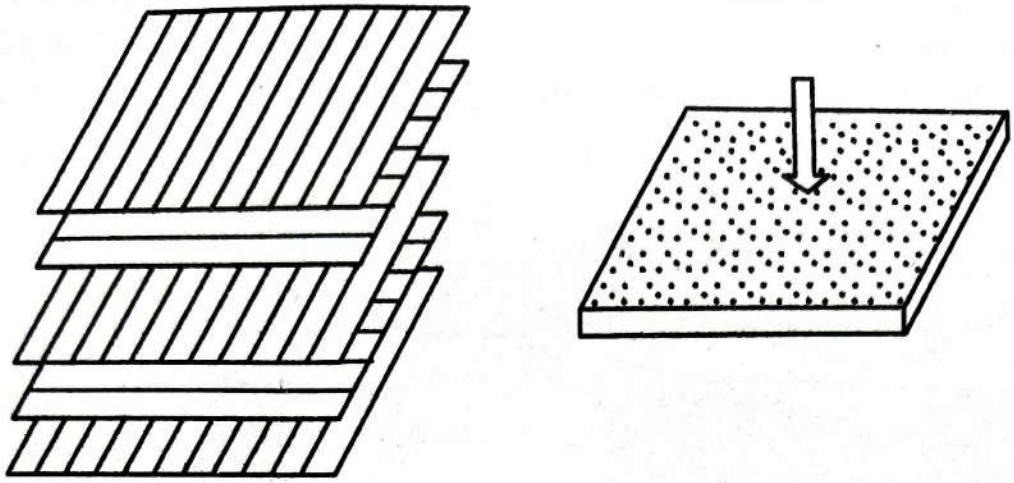
Structural composite is composed of both homogeneous and composite materials. Their properties depend on the properties of constituent materials and also on the geometrical design of the various structural elements.

Structural composites can be broadly classified as :

i) Laminar Composites and

ii) Sandwich Panels.

i) **Laminar Composites :** Laminar composite is composed of two-dimensional sheets or panels that have a preferred high-strength direction such as is found in wood and continuous and aligned fibre-reinforced plastics. The layers are stacked and subsequently cemented together such that the orientation of the high-strength direction varies with each successive layer **(Fig. 3.3)**. For example, adjacent wood sheets in plywood are aligned with the grain direction at right angles to each other. Laminations may also be constructed using fabric material such as cotton, paper or woven glass fibres embedded in a plastic matrix. A laminar composite has relatively high strength in a number of directions in the two-dimensional plane. The strength in any given direction is lower than it would be if all the fibres were oriented in that direction. For example, a relatively complex laminated structure is the modern ski.



(a) Stacking of successive oriented fibre-reinforced layers

(b) Fabricated laminar composite

Fig. 3.3 : Fibre-reinforced layers for a laminar composite

ii) **Sandwich Panels :** Sandwich panels are designed to be light-weight beams or panels having relatively high stiffness and strengths. A sandwich panel consists of two outer sheets or faces that are separated by and adhesively bonded to a thicker core (**Fig. 3.4**). Faces are made of a relatively stiff and strong material, typically aluminium alloys, fibre-reinforced plastics, titanium, steel or plywood.

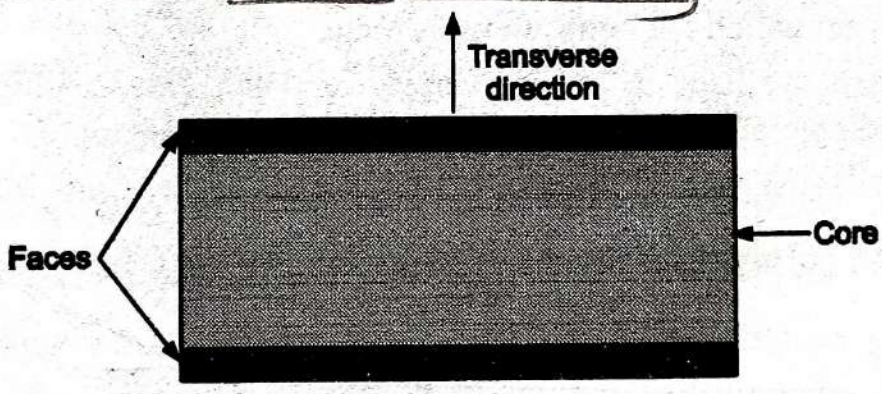


Fig. 3.4 : Schematic diagram showing cross section of a sandwich panel

Functions :

i) They impart high stiffness and strength to the structure.

ii) They must be thick enough to withstand tensile and compressive stresses that result from loading.

The core material is light-weight has a low modulus of elasticity. Typical "core" materials include synthetic rubbers, formed polymers, balsa wood and inorganic cements.

Core serves the following two structural functions.

i) It separates the "faces" and provides continuous support for the faces.

ii) They resist any deformations perpendicular to the face plane.

iii) It provides a certain degree of shear rigidity along planes which are perpendicular to the "faces".

Another popular core consists of a "honeycomb" structure thin foils that have been formed into interlocking hexagonal cells, with axes oriented perpendicular to the face plane. **Fig. 3.5.**

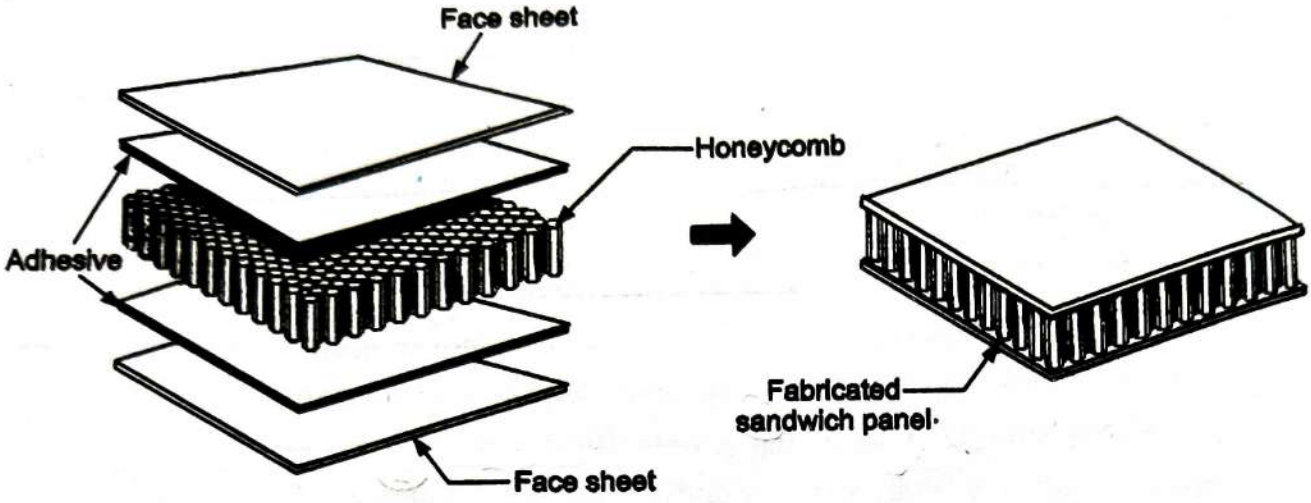


Fig. 3.5 : Schematic diagram showing construction of honeycomb core sandwich panel

The honeycomb material is normally either an aluminium alloy or aramid polymer. Strength and stiffness of honeycomb structures depend on cell size, cell wall thickness, and the material from which the honeycomb is made.

Sandwich panels are used in a wide variety of applications including roofs, floors, and walls of buildings; and in aeroplanes and aircraft (i.e. for wings, fuselage and tail-plane skins.).

3.7 APPLICATIONS OF COMPOSITE MATERIAL

i) Metal cutting equipment such as lathe tools, milling cutters and saws of various types, ~~represent one of the most important fields for sintered carbides with a proven record of success. They~~ are widely used for cutting all types of metals.

ii) Sintered carbides are also extensively used for machining non-metallic materials such as Ebonite, Bakelite and other plastics and also natural products including slate, marble, granite, coal and other types of rock.

iii) Cemented carbides are used in many grinding applications in the form of balls, grinding cylinders and also as mill liners. They give outstanding life together with minimum contamination of the product being ground.

iv) The gauges and plugs used for engineering inspection are made from cemented carbide to provide wear resistance and dimensional accuracy over long periods of continuous use.

v) Other applications of cemented carbides include ceramic spraying and burner nozzles, valve and valve seat inserts, and tyre stud inserts.

(4) High tensile strength so used in aerospace, sports equipments.

(5) Good surface finishing - making plywood, automotive parts, automative interoir.

vi) Alclad sheets are widely used for aircraft structures and skins to provide light weight, corrosion and fatigue resistance. They are also used as industrial siding and roofing panels.

vii) Copper clad stainless steel sheets has been effectively and economically used in roofing and as face sheets for wall panels, flashings and rain drainage, siding, window and door frames and roof-ventilators.

viii) Copper clad stainless steel utensils are widely used in cooking to provide rapid and more uniform heat distribution as compared to solid stainless steel.

ix) Glass fibre reinforced resins have been used for a variety of applications requiring high mechanical strength, such as automobile fenders and sailboat hulls.

x) Glass fibre reinforced plastics have a broad spectrum of applications in construction industry, electrical industry, transportation, agriculture, consumer goods, sports and leisure activities, industry etc.

xi) Asbestos reinforced phenolic resins were used for automotive brake linings.

3.8 BIO COMPOSITES

Bio-composites are materials which have natural fibres like plant fibres, and can either have a natural or synthetic polymer matrix. They are non-polluting and are progressively finding applications in various sectors mainly because they are lighter and sustainable.

3.8.1 Classification of Bio-Composites

Bio-composites are classified as follows:

1. Natural Fibre Reinforced Bio-Composites (NFRBCs):

Jute, hemp, flax, and bamboo are natural fibres, whose bio-composites are made up of the fibrous elements mixed with a polymer matrix. It is mainly used in the manufacture of automotive parts and furniture items.

2. Wood Polymer Composites (WPCs):

These bio-composites are made from wood fibres or sawdust, combined with a polymer matrix. They are primarily used in decking, outdoor furniture, and building materials.

3. Bio-based Composites:

Such materials are formulated from bioplastics, replacing the synthetic types. Some of the application include packaging, automotive industry, and health care appliances.

4. Hybrid Bio-Composites:

This is to integrate different fibre types to optimize the advantageous characteristics inherent in both the material categories of natural fibres and synthetic fibres.

3.8.2 Applications of Bio-Composites

Applications of Bio-composites are as follows:

1. **Automotive Industry:**

Used for making lighter automotive parts, thereby improving fuel efficiency and reducing emissions.

2. **Construction:**

Used in green building products, which include flooring, decking, and insulation.

3. **Packaging:**

Bio-composites are used for bio-friendly packaging materials that are biodegradable and hence help in reducing plastic waste.

4. **Furniture:**

Used in making lightweight and strong furniture items that are sustainable.

5. **Medical Devices:**

Some bio-composites are biocompatible and therefore applied in medical fields such as prosthetics, implants, and wound dressings.

3.9 REVIEW QUESTIONS

1. What are composite materials? Give their classification.

Ans. Refer Section 3.1 and 3.3.

2. Write an informative note on
   (i) Laminar composites, (ii) Sandwich panel.

Ans. Refer Section 3.6.

3. What is a cermet?

Ans. Refer Section 3.4.

4. What are whiskers?

Ans. Refer Section 3.5.

5. What is a fibre reinforced composite?

Ans. Refer Section 3.5.

6. What are composite materials? What are their properties?

Ans. Refer Section 3.1 and 3.2.

7. Discuss some important types of fibre reinforced composites.

Ans. Refer Section 3.5.

8. What are the characteristics of composites?

Ans. Refer Section 3.2.

9. Give an example of layered composite.

Ans. Refer Section 3.6.

10. What are particulate composites?

Ans. Refer Section 3.4.

11. Name the different fibres used for preparing composites.

Ans. Refer Section 3.5.

12. Write a note on Bio-composites?

Ans. Refer Section 3.8.

13. Define and give classification of Bio-composites.

Ans. Refer Section 3.8 and 3.8.1.

14. Give the applications of Bio-composites.

Ans. Refer Section 3.8.2.

15. Give the applications of composites.

Ans. Refer Section 3.7.

3.10 UNIVERSITY QUESTIONS

May 2008

1. Write the applications of composite materials. (3M)

Ans. Refer Section 3.7.

2. Define composite materials. Give the classification of composite materials. Explain laminates. (5M)

Ans. Refer Section 3.1, 3.3 and 3.6.

3. What are the characteristic properties of composite materials? (3M)

Ans. Refer Section 3.2.

Dec. 2008

1. What are composite materials? Give their classification. (3M)

Ans. Refer Section 3.1 and 3.3.

2. What are structural composites? Give their types and applications. (5M)

Ans. Refer Section 3.6.

3. What are fibre reinforced composites? Explain their types. (5M)

Ans. Refer Section 3.5.

May 2009

1. Write a short note on structural composites. (5M)

Ans. Refer Section 3.6.

Dec. 2009

1. Give classification of composite materials. (3M)

Ans. Refer Section 3.3.

2. Explain characteristics of composite materials. (3M)

Ans. Refer Section 3.2.

3. Write note on glass fibre reinforced composites. (5M)

Ans. Refer Section 3.5.

May 2010

1. What are composites? What are their advantageous characteristics? (3M)

Ans. Refer Section 3.1 and 3.2.

2. Explain laminar and sandwiched panel with suitable example. (6M)

Ans. Refer Section 3.6.

3. Explain in detail fibre reinforced composites. (6M)

Ans. Refer Section 3.5.

4. What are the important applications of composites? (4M)

Ans. Refer Section 3.7.

Dec. 2010

1. Give the classification of composite materials. (3M)

Ans. Refer Section 3.3.

2. Write a note on structural composites. (5M)

Ans. Refer Section 3.6.

3. What are composite materials? Describe fibre reinforced composites. (5M)

Ans. Refer Section 3.1 and 3.5.

May 2011

1. What are the characteristic properties of composite materials? (3M)

Ans. Refer Section 3.2.

2. What are structural composites? Give their types and applications. (5M)

Ans. Refer Section 3.6.

Dec. 2011

1. What are fibre composites? (3M)

Ans. Refer Section 3.5.

May 2012

1. Give the classifications of composite materials. (3M)

Ans. Refer Section 3.3.

2. What are composite materials? Describe fibre reinforced composites. (5M)

Ans. Refer Section 3.1 and 3.5.

Dec. 2012

1. What are composite materials? What are the applications of composites? (3M)

Ans. Refer Section 3.1 and 3.7.

2. Explain structural composites. (5M)

Ans. Refer Section 3.6.

3. What are fibre-reinforced composites? (4M)

Ans. Refer Section 3.5.

May 2013

1. Give the classifications of composite materials. (3M)

Ans. Refer Section 3.3.

2. Explain Laminar composites with suitable diagram. (4M)

Ans. Refer Section 3.6.

Dec. 2013

1. Write a note on 'sandwich panel' type layered composites. (4M)

Ans. Refer Section 3.6.

May 2014

1. Give classification of composite materials. (3M)

Ans. Refer Section 3.3.

2. Write a note on 'sandwich panel' type layered composites. Mention their applications. (4M)

Ans. Refer Section 3.6.

Dec. 2014

1. What are composite materials? Mention any four characteristic properties of composite materials. (3M)

Ans. Refer Section 3.1 and 3.2.

2. Explain laminar composites with suitable examples. (4M)

Ans. Refer Section 3.6.

May 2015

1. Define Composite materials. (3M)

Ans. Refer Section 3.1.

2. Write a note on 'Sandwich panel' composite. (4M)

Ans. Refer Section 3.6.

December 2015

1. What are composite materials? Mention any four characteristics of composite materials. (3M)

Ans. Refer Section 3.1 and 3.2.

2. Explain 'Sandwich panel' composite. Mention their application. (4M)

Ans. Refer Section 3.6.

May 2016

1. Give classification of composite materials. (3M)

Ans. Refer Section 3.3.

2. What are glass fibre reinforced composites? Outline their properties, applications and limitations. (4M)

Ans. Refer Section 3.5.

December 2016

1. Give classification of composite materials. (3M)

Ans. Refer Section 3.3.

2. Write a note on Sandwich panel type layered composites. (4M)

Ans. Refer Section 3.6.

CHAPTER 4

PLASTICS AND ELASTOMERS

CONTENTS

4.1 Introduction to Plastics
4.2 Classification of Plastics
4.3 Compounding of Plastics
4.4 Applications of Plastics
4.4.1 Industrial and Engineering Applications
4.5 Commercial Plastics
4.6 Introduction to Rubbers or Elastomers
4.7 Natural Rubber
4.7.1 Trans-Polyisoprene (Gutta-Percha)
4.7.2 Structure of Cis and Trans Polyisoprene
4.8 Drawbacks of Natural Rubber
4.9 Vulcanization of Rubber
4.10 Applications of Rubber
4.11 Commercial Rubbers
4.12 Numericals
4.13 Review Questions
4.14 University Questions

4.1 INTRODUCTION TO PLASTICS

The word plastic originated from Greek, meaning a material which can be moulded or formed into any shape of one's own choice. In a broad sense, a plastic refers to a material which exhibits plasticity i.e. the ability to get deformed or to undergo change of shape

under pressure. Plastic may be defined as organic materials of high molecular weight, which can be moulded into any desired form, when subjected to heat and pressure in the presence of a catalyst. They are relatively new materials of construction which rapidly found extensive industrial application. In recent years, they have attained great importance in every walk of our life, due to their certain unique properties as follows:

(i) Lightness in weight.

(ii) Good thermal and electrical insulation.

(iii) Good corrosion resistivity.

(iv) Easy workability and adhesiveness.

(v) Low fabrication cost and decorative surface effect.

(vi) Insect resistivity, good strength and toughness.

(vii) Chemically inert to action of light, oils, acids and dampness.

(viii) Low maintenance cost and high refractive index.

Plastics must be differentiated from resins. In technical sense, resins are the basic binding materials which form a major part of plastics and which actually have undergone polymerization and condensation reactions, during their preparation. Thus, there is a little difference between plastic and resin. These two terms are currently used interchangeably. The resin may be liquid or viscous or solid but it can be polymerized further to give required shape in the mould. During the moulding, compounding agents like fillers, colourants, and catalysts may be added in them. These ingredients provide sturdiness and other desired characteristics to polymers.

4.2 CLASSIFICATION OF PLASTICS

On the basis of setting manners in final shape stage of manufacture on application of heat and pressure, plastics may be categorized as :

(i) Thermoplastics (TP).

(ii) Thermosetting plastics (TS).

(i) Thermoplastics :

They may be defined as those which can be softened on heating and harden on cooling reversibly. They soften on heating and remain in the same state till hot. On cooling, they acquire rigidity and hardness. The changes involved in heating and cooling process are purely of the physical nature. The chemical nature of the material is not affected. These plastics have linear polymer chains or negligibly branched chains. They are obtained by addition polymerization.

Mechanically, these plastics are soft. They have lesser tensile strength, better flexibility and poor abrasion resistance. Their molecular weight is relatively less and are soluble in certain organic solvents. Some of the examples are polyethene, PVC, polystyrene, polyvinyl acetate, polyacrylonitrile, styrene acrylonitrile co-polymer, nylons, polyesters etc.

(ii) Thermosets or Thermosetting plastics :

Thermosetting plastics are those which set up on heating and can not be reformed when once they are set. In general, they are the plastics which are formed by condensation. They have three dimensional network structures and have high molecular weights. They have predominant covalent cross links between the long chains which are responsible for the three dimensional network structure.

When they are moulded, additional cross-linkings are formed between the long chains leading to increase in molecular weight. Due to the cross-linkings formed, they acquire properties as hardness, toughness, brittleness, non-swelling and non-softening etc. The strength of bonds is retained on heating and they can be softened or reclaimed once they are cured.

Some of the examples of thermosetting plastics are phenol formaldehyde, polyurethanes, melamine formaldehyde, urea formaldehyde etc.

Comparison between Thermoplastics and Thermosetting :

Thermoplastics (TP)	Thermosetting (TS)
(1) Soften on heating and stiffen on cooling, reversibly, by the action of heat.	(1) On heating, they are converted into an infusible mass and once set, can't be reshaped.
(2) They are formed by addition polymerization.	(2) They are formed by condensation polymerization.
(3) Contain long chains with negligible cross-links.	(3) Contain three dimensional array of network.
(4) They can be remoulded, reshaped and can be used.	(4) They can not be remoulded and reused.
(5) They are usually soluble in organic solvents; some swell up in solvent.	(5) They are usually insoluble in any solvents.
(6) They can be reclaimed from the wastes.	(6) They can not be reclaimed.
(7) They are usually soft, weak and less brittle.	(7) They are usually hard, strong and more brittle.

(8) They have low molecular weight as compared to thermosetting.	(8) They have high molecular weight as compared to thermoplastics.
(9) Neighbouring polymeric chains are held together by weak Van der Waal's forces.	(9) Neighbouring polymeric chains are held together by strong covalent bonds in the form of cross-links.
(10) Heating and cooling do not alter chemical nature. Only physical changes are involved on heating.	(10) Chemical changes occur on heating.
(11) For example, polyethylene, polystyrene, PVC, Teflon, nylon etc.	(11) For example, polyurethane, phenol formaldehyde, urea formaldehyde.

4.3 COMPOUNDING OF PLASTICS

In order to impart certain definite properties to finished products, plastic is compounded with other ingredients. These ingredients either discharge a useful function during moulding or impart some useful property to the finished product. This is called a mixture. The various constituents added are :

(1) Binders, (2) Fillers, (3) Plasticizers, (4) Dyes and pigments, (5) Lubricants, (6) Catalysts, (7) Stabilizers.

(1) Binders : Usually, plastic is classified depending on the type of binder used for its manufacture. As the name implies, the main purpose of binder is to hold the other constituents of the plastic together. It also determines the type of treatment needed to mould the articles from the plastic material. A binder may compose of 30 to 100% of the plastics.

The binders used may be natural or synthetic resins or cellulose derivatives. In presence of catalyst, they get converted into infusible cross-link form. They also influence the properties of the plastic. For example, if low molecular weight binder is used, the plastic gets moulded very easily.

(2) Fillers : Fillers are the substance added to plastic to serve the following purposes:

(a) They reduce the cost of the plastic.

(b) They reduce shrinkage on setting and brittleness.

(c) They impart better tensile strength, hardness of the plastic, opacity, finish and workability. Fillers are added to impart special characters to the finished products. For example, (i) Barium salts make plastic impervious to X-rays. (ii) Asbestos provide corrosion and heat resistances. (iii) Carborundum, quartze, mica provide extra hardness. (iv) Addition of carbon black increases tensile strength. (v) Shredded textiles increase tensile impact strength.

In addition to above, the other materials in common use as fillers are cotton, corn husks, graphite, clay, paper pulp, wood flour, pumice, metallic oxides (for example, ZnO, PbO), saw dust and metal powders (such as Fe, Cu, Pb and Al). The proportion of the filler added can reach as high as 50% of the plastic.

(3) Plasticizers : The important function of plasticizers is to improve plasticity and flexibility, so as to reduce the temperature and pressure required for moulding. They play very important role in determining the properties of finished product and hence are chosen accordingly. Their plasticizing properties are believed to be mainly due to the partial neutralization of the intermolecular forces of attraction in the resin molecules. They impart greater freedom of movement between the polymeric macromolecules of the resin. (thus increases flexibility and plasticity). At the same time, it reduces its strength and decreases its chemical resistance.

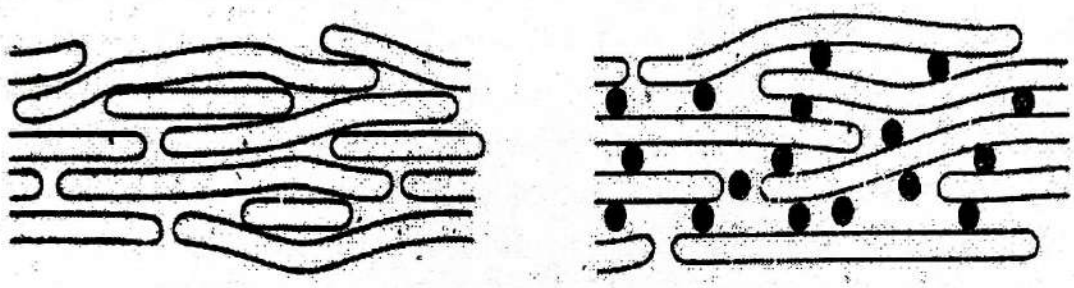


Fig. 4.1 : Action of plasticizer in plastics

The proportion of plasticizers can be up to 60% of the plastics. They are often used with thermosetting plastics. For instance, cellulose derivatives have the tendency to discolour when moulded unless moulding temperature is reduced by the addition of suitable plasticizer.

Most commonly used plasticizers are vegetable oils, camphor, esters of oleic, stearic or phthalic acids, tributyl phosphate, triphenyl phosphate, triacetin etc. When used with cellulose acetate, camphor increases surface hardness; tributyl phosphate and triphenyl phosphate impart flameproofness; triacetin and tributyl phosphate improves toughness.

(4) Dyes and pigment : Colour appeal is often of prime importance in high polymer artifacts. Thus, they are meant for providing decorative colours to the plastic. The main colouring materials are organic dyestuffs and opaque inorganic pigments.

Table 4.1 : Materials used as colourants

Colorants	Imparted colour
Ultramarine	Blue
Carbon black	Black
Calcium carbonate	White

Zinc oxide	White
Chromium trioxide	Green
Ferric oxide	Red
Antimony sulphide	Crimson red

(5) Lubricants : Theses additives promote a good finish to the plastic materials, in addition to improving the flow characteristics and friction reduction in the processing machines. Waxes, oils, stearates, oleates and soaps are employed to make the moulding of the plastics easier and help in providing a glossy finish to the products.

(6) Catalyst : Accelerators are added in case of thermosetting plastics to accelerate the polymerization of fusible resin during moulding process, into cross-linked infusible form. Catalysts which are used for this purpose are hydrogen peroxide, benzoyl peroxide, acetyl sulphuric acid, ammonia and its salts, metals like Ag, Cu and Pb; metallic oxides such as zinc oxide etc.

(7) Stabilizers : Alkaline earth oxides, organometallic salts, epoxy compounds and amine type compounds serve as stabilizers, which are added to polymers to prevent their degradation. Their purpose is to improve the thermal stability during processing. For example, during the moulding of vinyl chloride and vinylidine chloride polymers, heat stabilizers are used, as these polymers show a tendency to undergo decomposition and discolouration at the moulding temperature. Lead salts like white lead, lead chromate, litharge, red lead serve as opaque moulding compounds. Stearates of lead, cadmium and barium are transparent moulding compounds.

4.4 APPLICATIONS OF PLASTICS

Plastics have assumed very important position as engineering materials. Their importance can be compared with steel and ceramics. Some of the important uses of plastics are as follows:

(i) For making electrical goods.
(ii) In aeronautical engineering.
(iii) For making furniture.
(iv) For making handles for tools and covers of machines.
(v) For making special types of paints.
(vi) For making floor and wall linings.
(vii) For making electrical appliances such as plugs, switches, holders, radio and T.V. cabinets.
(viii) As water softening agent.

(ix) For making synthetic fibres like nylon, terylene and making adhesives.

(x) For making household articles like combs, toys, trays, toilet goods, lenses, films, tooth brush bristles, syringes etc.

(xi) For making bearings for propellar shafts used in paper industry and rolling mills.

(xii) For heat and sound insulation in cold storage, refrigeration, air conditioning buildings, theaters, auditoriums and for packing works.

(xiii) For making overhead water tanks and pipes to convey water, oils, gases, chemicals etc.

(xiv) For making hoses, water tubes, electrical cables, floor tiles, gramophone records, machine parts, telephone parts, seat cover etc.

(xv) For preparing decorative laminates and mouldings.

(xvi) For making films for water proofing, damp proofing and curing of concrete.

4.4.1 Industrial and Engineering Applications

(1) Polyethene :

Properties : It is rigid, waxy, non-polar material, higher tensile strength, extreme flexibility and chemical and moisture resistance.

Uses : For making high frequency insulator parts, bottle caps, flexible bottles, kitchen and domestic appliances, toys, sheets for the packing materials, chemical plants, tubes, pipes etc.

(2) Polyvinyl chloride (PVC) :

Properties : Chemically inert, resistance to light, atmospheric oxygen, inorganic acids and alkalies, high softening point, greater stiffness and rigidity.

Uses : It is used for making sheets used in tank linings, light fittings, safety helmets, refrigerator components, tyres, cycle and motor cycle mud guards.

(3) Polyvinyl acetate :

Properties : It is resistant to water, atmospheric oxygen and chemicals. Soluble in organic solvents and acids. It is heat resistant.

Uses : Used for making records, chewing gums, surgical dressings, paints, lacquors, plastic emulsions, coating, card boards, wrapping paper, leather, textiles etc.

(4) Polystyrene (PS) :

Properties : It is light stable, moisture resistant, electrical insulating, resistant to acids, chemical resistant. It has unique property of transmitting light through curved sections.

Uses : In moulding of articles like toys, combs, buttons, buckles, radio and television parts, battery cases, high frequency electric insulators, lenses, indoor lighting panels etc.

(5) Polytetrafluoroethylene (TEFLON) :

Properties : It is very tough. High chemical and heat resistant. It has good electrical and mechanical properties. It has low coefficient of friction.

Uses : As insulating material (for motors, cables, wires, fittings etc.) and for making gaskets, packings, pumps parts, tank lining, chemical carrying pipes, tubings and tanks etc.; for coating and impregnating glass fibres, asbestos fibres and clothes; in non-lubricating bearing etc.

(6) Polycarbonates :

Properties : It has high impact and tensile strength.

Uses : For preparing moulded domestic wear, housing for apparatus and electrical insulator in electronics and electrical industries.

(7) Polyamides (Nylon 6, Kevlars) :

Properties : Easily mouldable, tough, strong abrasion resistant, chemical resistant and low co-efficient of friction.

Uses : They have applications in watch straps, automobile tyres, gears, unlubricated bearings, high tensile ropes, electrical mountings etc.

(8) Solid Silicones :

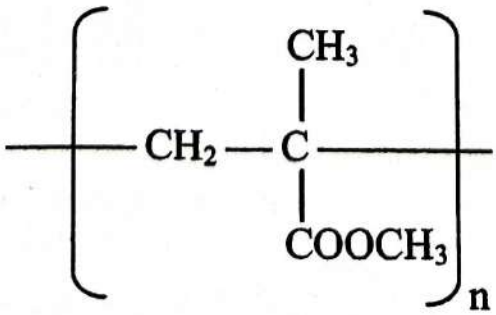
Properties : It has good electrical insulating properties, outstanding heat resistance, chemical inertness, good water repellency, resistance to weathering etc.

Uses : They are used in high voltage insulators, high thermally stable moulding and high temperature insulating foams.

4.5 COMMERCIAL PLASTICS

(1) Polymethyl methacrylate or Lucite or Plexiglass :

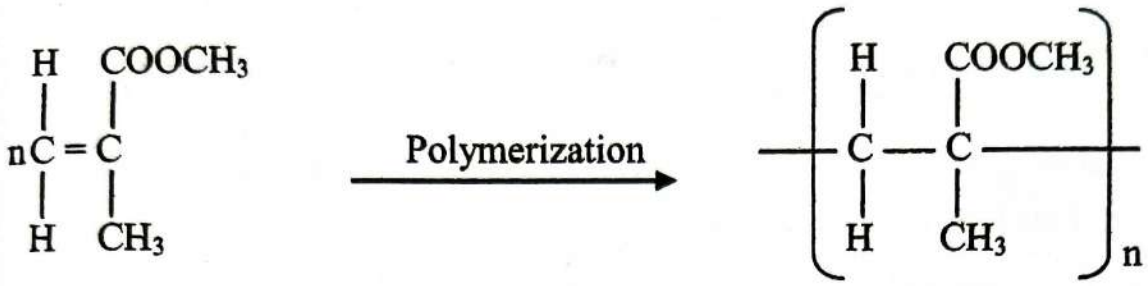
Polymethyl methacrylate is the best known plastic from the acrylates because of its outstanding optical properties. This polymer has the following structure.



Polymethyl methacrylate (PMMA)

Polymethyl methacrylate (PMMA) :

The monomer used is methyl methacrylate (an ester of methyl acrylic acid is produced from acetone). Polymethyl methacrylate is obtained by polymerization of methyl methacrylate in presence of acetyl peroxide or hydrogen peroxide. It is an acrylic polymer.



Methyl methacrylate (MMA)

Polymethyl methacrylate (PMMA)

Properties :

(1) It is colourless, transparent, hard and fairly rigid material.

(2) It is amorphous because of the presence of bulky side groups in the molecules.

(3) It has high softening point of about 130°C to 140°C and becomes rubber like at a temperature above 65°C.

(4) It has high optical transparency.

(5) It has high resistance to sunlight and ability of transmitting light accurately, even in curved sections.

(6) It has low chemical resistance to hot acids and alkalies.

(7) It has low scratch resistance.

Uses :

(1) It is used for automotive applications such as in tail and signal light lenses, dials, medallions etc.

(2) For making aircraft light fixtures, bomber noses gun turrets, cockpit canopies, transparent models of complicated mechanisms.

(3) For making bone splints, artificial eyes, dentures, emulsions, paints, adhesives, wind screens, jewellery, T.V. screens, guards etc.

(4) Its sheets are used for signs, glazing skylights and decorative purposes.

(2) Polytetrafluoroethylene (PTFE) :

It is obtained by polymerization of tetrafluoroethylene, under pressure in the presence of benzoyl peroxide.

Properties :

(1) It is very tough with high softening point.

(2) It has high chemical and heat resistance.

(3) It has high density and waxy touch.

(4) It has good electrical and mechanical properties.

(5) It has low coefficient of friction.

Uses :

(1) As an insulating material, it is used for motors, cables, wires, fittings etc.

(2) It is used for making gaskets, packings, pumps parts, tank lining, chemical carrying pipes, tubings and tanks etc.

(3) It is used for coating and impregnating glass fibres, asbestos fibres and clothes.

(4) It is used in non-lubricating bearing etc.

4.6 INTRODUCTION TO RUBBERS OR ELASTOMERS

Christopher Columbus brought to Spain in 1498 an exudates sample from the tree Hevea Brasiliensis from South America. It was first used by South American Indians in the name of Cautchouc. Later, Priestley (1770) discovered that it could rub pencils marks and henceforth it became known as rubber.

Rubbers (also known as elastomers) are high polymers, which have elastic properties in excess of 300 percent. A rubber band can be stretched to 4 to 10 times its original length but it returns to its original length as soon as the stretching force is released. Likewise, a rubber block can be compressed but it returns to its original shape and dimensions as soon as the load is withdrawn. Such elastic deformation can be explained by the fact that an elastomer molecule is not straight chained but is in the form of coil that can be stretched like a spring as shown in **Fig 4.2.**

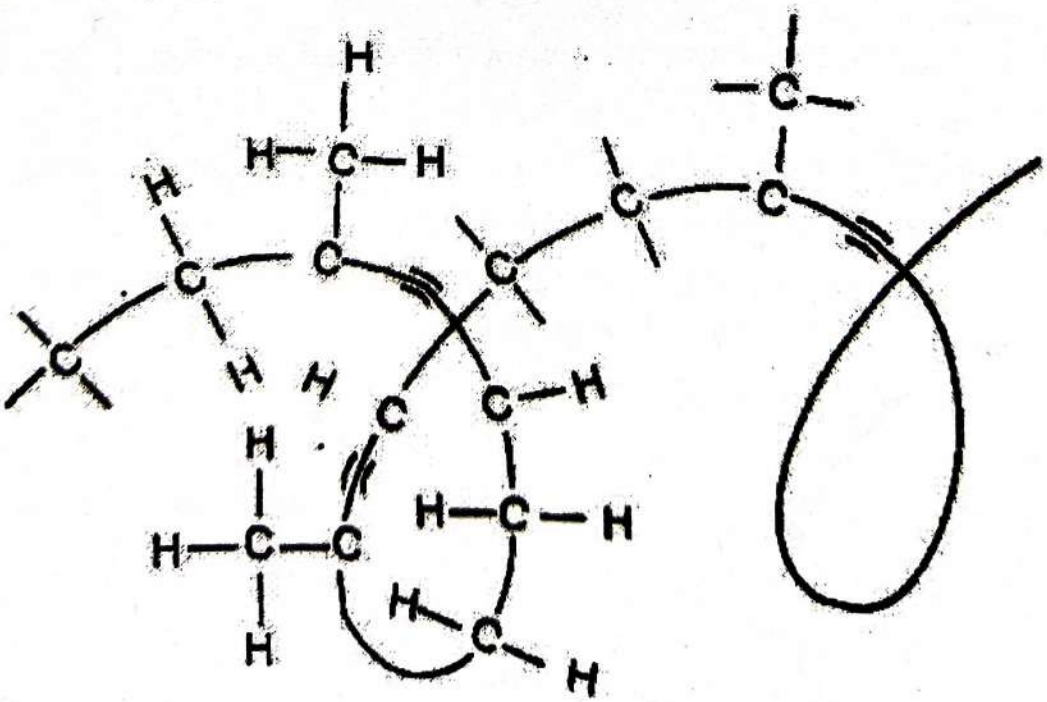


Fig. 4.2 : Schematic representation of coiled elastomer chain of natural rubber (polyisoprene)

Thus, the elasticity of rubber can be attributed to lengthening and shortening of these polymeric spring like chains.

Unstretched rubber is amorphous. As it is stretched, the macromolecules present in it become partly aligned with respect to one another thereby causing crystallization and stiffening of the material due to increased forces between the molecules. As soon as the deforming stress is withdrawn, the chains revert to their original coiled status and the material again becomes amorphous.

Rubbers or elastomers can be natural or artificial (i.e. synthetic). By distilling rubber, Faraday (1826) obtained isoprene. Isoprene is a diene as shown by Tiden (1889); hence rubber was represented as $(C_5H_8)n$.

4.7 NATURAL RUBBER

Natural rubber is a polymerized form of isoprene (2-methyl-1, 3-butadiene).

$$CH_2 = \underset{\displaystyle CH_3}{\overset{\displaystyle |}{C}} - CH = CH_2$$

Natural rubber is obtained from the plant known as Hevea brasiliensis which is originally from Brazil and is cultivated in plantations mainly in tropical regions in South East Asia, especially in Malaysia and Indonesia, India, Thailand etc. The source of natural rubber is milky liquid, known as latex, which is a suspension containing very small particles of rubber. Although latex from these plants varies in composition, a typical composition is as

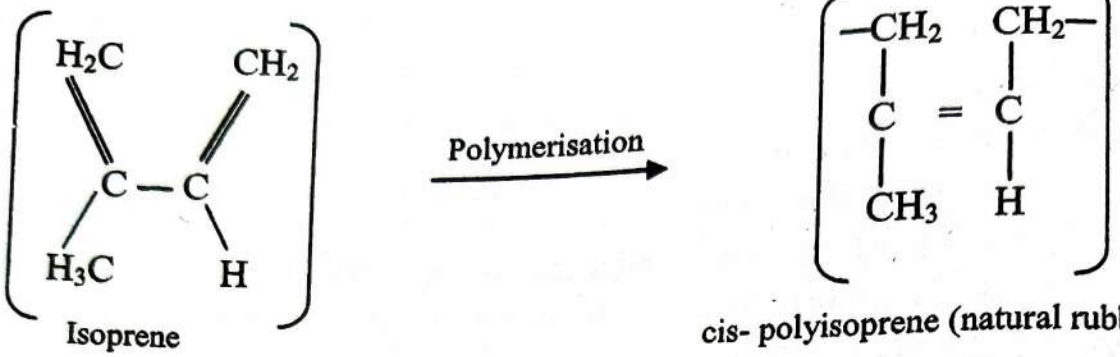
Total solid content	**36% (33% in dry rubber content)**
Proteinous substance	1 - 1.5 %
Ash	Less than 1 %
Sugar	1 %
Water	≈ 60 %

Latex is obtained by making small cut in the bark of the rubber trees. Such tapping of latex from the cuts is done at the intervals of six months. The latex thus collected from the trees is taken to processing center.

Processing of Latex :

Latex is diluted to contain between 15 to 20% of rubber. Then it is filtered to eliminate any dirt present in it. Acetic acid or formic acid is then added to the diluted latex to get the pH 4 to 5. The acidic condition catalyses the polymerization of isopropene monomer. The rubber is coagulated to soft white mass. The coagulated mass (coagulum) is washed and then treated further.

Polymerization of isopropene molecules to form long coiled chains of cis-polyisopropene.



Isoprene

cis- polyisoprene (natural rubber)

(a) Crepe Rubber :

(i) A small amount of sodium bisulfite is added to the coagulum to bleach the rubber and it is allowed to drain for two hours.

(ii) It is passed through a 'creping machine' which consists essentially of two rollers (about 3 mm apart and 50 cm wide) with longitudinal grooves, upon which water is sprayed.

(iii) Due to creping, spongy coagulum is converted into a sheet (1 mm thickness) which possesses an uneven rough surface resembling crepe paper.

(iv) Crepe rubber can be used as it is or may be compounded, vulcanized and then used.

(b) Smoked Rubber :

(i) Coagulation is carried out in long tanks (about 1 m wide and 30 cm deep having sides with vertical groves about 4 cm apart fitted with metal plates) with diluted acetic acid or formic acid with stirring.

(ii) The tanks are kept undisturbed for about 16 hours.

(iii) The tough slabs of coagulum formed are then removed.

(iv) The slabs thus formed are passed through a series of smooth rollers with decreasing clearance space in between them, on which water is sprayed.

(v) Thin rubber sheets having 'ribbon like pattern' exposes greater surface and this facilitates consequent drying.

(vi) These sheets are hung for about 4 days in a smoke house at temperature 40°C to 50°C.

(vii) The dried, smoked rubber is amber in colour and translucent, resistant to action of bacteria and fungi and can be used after vulcanization.

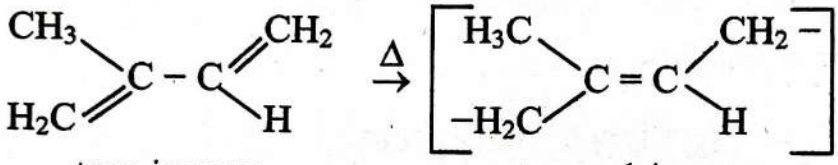
4.7.1 Trans-Polyisoprene (Gutta-Percha)

Gutta-percha is a thermosoftening plastic and not a rubber. It is obtained from mature leaves of dichopsis gutta and palagum gutta tress grown mostly in Broneo, Malaya and Sumatra.

Preparation :

Mature leaves are ground carefully, treated with water at about 70°C for half an hour. Then the mixture is poured into cold water when gutta percha floats on water surface and is removed.

The polymerization reaction of trans-isoprene can be shown as follows:



trans-isoprene

trans-polyisoprene
(gutta-percha)

Properties :

(i) At room temperature, it is tough and horny substance.

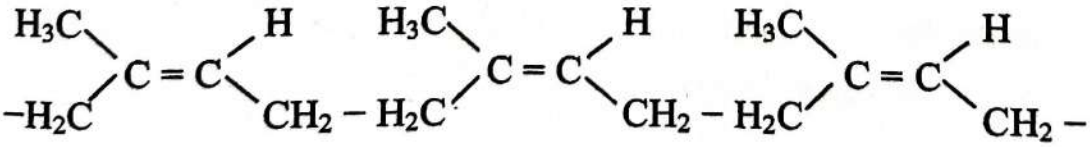
(ii) It softens and become tacky at 100°C.

(iii) It is soluble in aliphatic hydrocarbons.

4.7.2 Structure of Cis and Trans Polyisoprene

The natural rubber is mainly cis-1, 4 polyisoprene. In cis-1, 4 polyisoprene, carbon number 1 and 4 are on the same side of double bond.

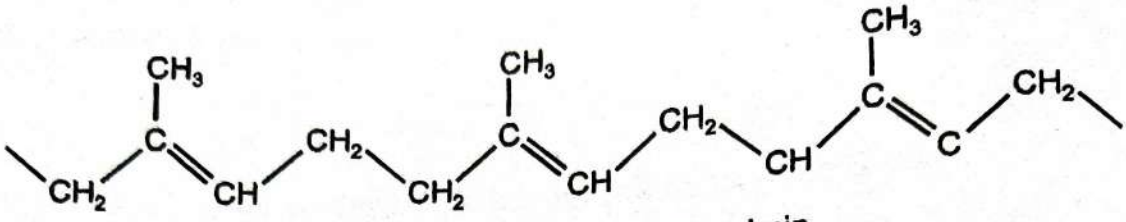
The natural rubber is unsaturated aliphatic hydrocarbon polymer of very regular structure.



Segment of natural rubber polymer chain

It has a very regular chain structure. It undergoes crystallization on stretching and at high elongation, it has high tensile strength. This is known as strain induced crystallization. On removal of load, the crystals melt and rubber chains retract to their normal configuration, as intermolecular forces between them are very weak. This contributes to the mechanical properties of natural rubber.

There is another structural isomer of polyisoprene, trans-1, 4 polyisoprene called gutta percha. In this structure, carbon number 1 and 4 are on opposite side off double bond.



Segment of gutta - percha polymer chain

Trans-1, 4-polyisoprene

The molecule is highly symmetrical and exists in crystalline form. The crystallinity is a result of close packing of polymer chains (as they can fit together due to their zig-zag structure). It is much harder and less soluble.

4.8 DRAWBACKS OF NATURAL RUBBER

(1) As it becomes soft at higher temperature and brittle at lower temperature, can be used in the temperature range of 10°C to 60°C.

(2) It is very weak with tensile strength only 200 kg/cm^2.

(3) It has large water absorption capacity.

(4) It is non resistant to non polar solvents like vegetable and mineral oils, gasoline, benzene etc.

(5) It is attacked by oxidizing agents like nitric acid, concentrated sulphuric acid, chromic acid, sodium hypochlorite etc.

(6) It has little durability.

(7) If stretched to a great extent, suffers permanent deformation, because of sliding of some molecular chains over each other.

(8) It perishes due to oxidation in air.

(9) It swells considerably in organic solvents.

(10) It possess marked tackiness property.

4.9 VULCANIZATION OF RUBBER

Vulcanization is very widely used in rubber technology to effect cross-linking for removing the drawbacks in the natural rubber.

The vulcanization process was discovered by Goodyear in 1839. He used sulfur to cross-link polyisoprene molecules in natural rubber. Ever since, many studies have been carried out on vulcanization of natural as well as synthetic rubbers.

Definition :

Vulcanization is the process in which rubber is transformed from its plastic condition into elastic state by improving the degree of cross-linking between chains in it.

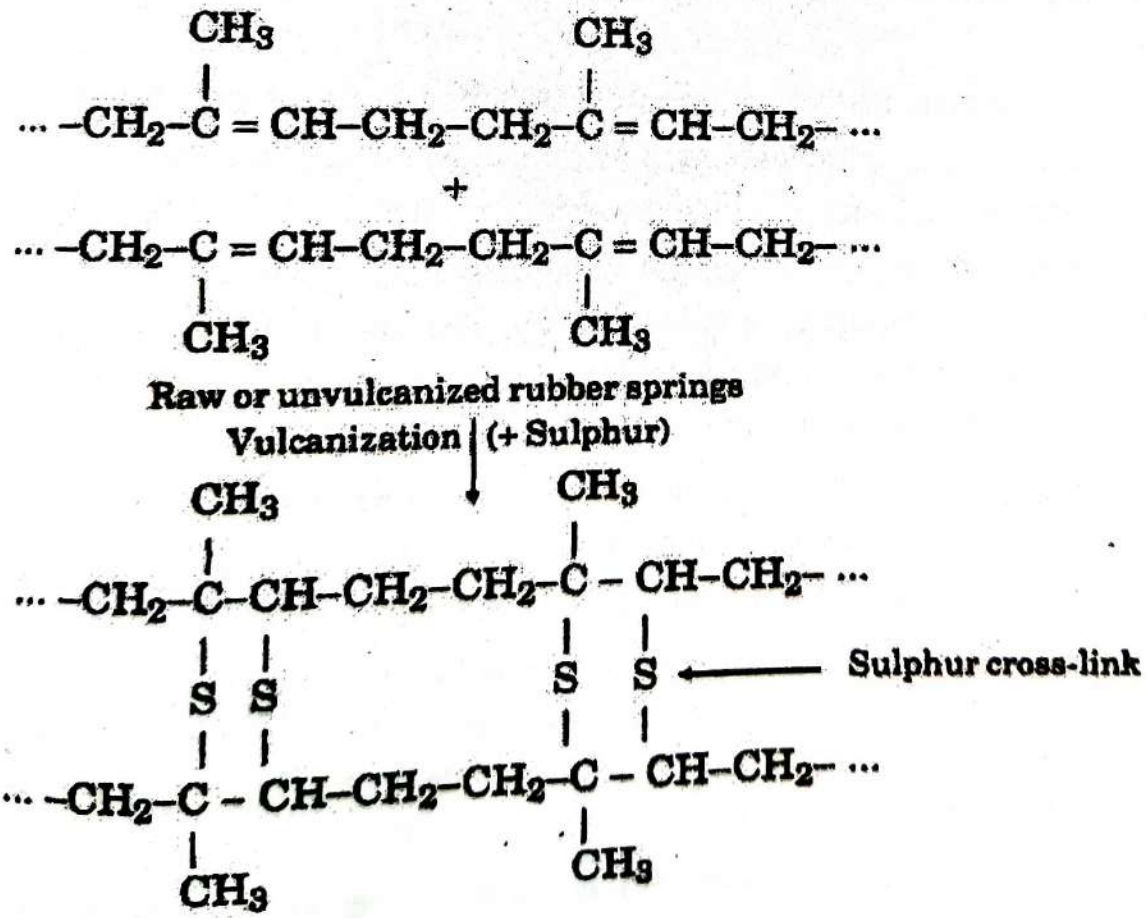
Process :

To improve the property of rubber, it is compounded with some chemicals like sulphur, benzoyl chloride, hydrogen sulphide etc. Most important is addition of sulphur. The process consists of heating the raw rubber with sulphur to 100-140°C. The added sulphur combines chemically at the double bonds of different rubber springs. So, vulcanization serves to stiffen the material by anchoring and preventing intermolecular movement of rubber springs. The extent of stiffness of vulcanization rubber depends on the amount sulphur added.

The reaction of sulphur with rubber is possible in two different ways :

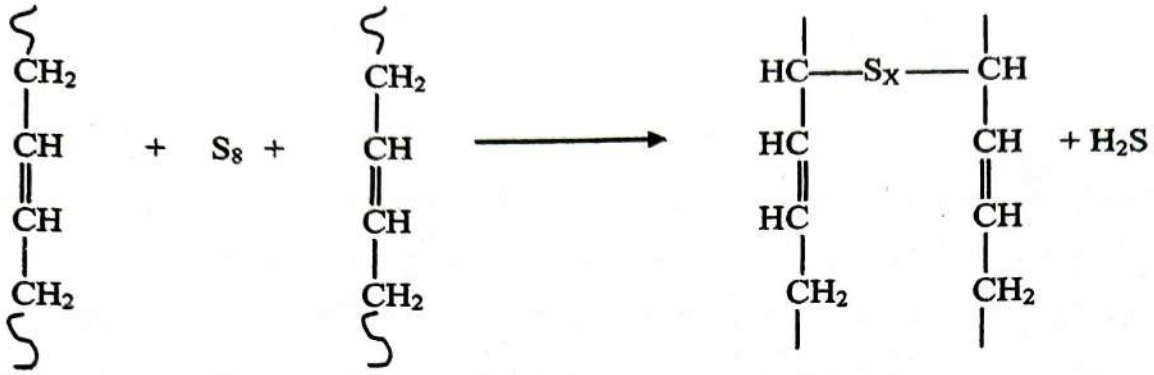
(a) Addition of sulphur at the double bond :

Sulphur or related compounds react with rubber molecules to effect cross-linking as follows :



(b) Addition of sulphur without affecting the double bond :

Sulphur can add to rubber by eliminating the double bond as shown below.



Vulcanization can be carried out in different ways :

(1) The article to be vulcanized is heated with steam under pressure.

(2) The article is immersed in hot water under pressure.

(3) By heating the article in air or in carbon dioxide.

(4) By passing steam directly into the article such as fire hose.

(5) By vulcanizing the article in the mould in which it is shaped.

For imparting desired properties to rubber, various additives are added as follows :

(i) **Vulcanizing Agent :** Most commonly used vulcanizing agent is sulphur. Along with sulphur, other compounds such as thioacids, mercaptans, benzoyl chloride, trinitro benzene, H_2S etc.

(ii) **Accelerators :** They are meant for catalyzing the vulcanization process thus reducing the time required for vulcanization. The inorganic accelerators include lime, magnesia, litharge and white lead whereas organic accelerators include aldehyde, amines, thiocarbamates, etc.

(iii) **Antioxidants :** These are the substances when used in small quantities (about 1%) retard the deterioration of rubber by light and air. They are complex organic amines like phenyl naphthyl amine, phenolic substance and phosphites.

(iv) **Reinforcing agents :** These substances are added to give strength, rigidity and toughness to the rubber and may form as much as 35% of the rubber compound. The commonly used reinforcing agents include carbon black, ZnO, $MgCO_3$, $BaSO_4$, $CaCO_3$ and some clays.

(v) **Inert fillers :** The main function of the inert fillers are to alter the physical properties of the mix to achieve simplification of manufacturing operations or to lower the cost of product.

Advantages of Vulcanization :

(1) It has good tensile strength and extensibility.

(2) It has excellent resilience, i.e. it returns to the original shape, when the deforming load is removed.

(3) It possesses low water absorption tendency.

(4) It has higher resistance to oxidation, wear and tear abrasion.

(5) It is better electrical insulator.

(6) It is resistant to organic solvents (petrol, benzene), fats and oils.

(7) It has slight tackiness.

(8) It has useful temperature range of −40°C to 100°C.

(9) It is easy to manipulate the vulcanized rubber to produce the desired shape.

Comparison of properties of raw rubber with vulcanized rubber :

Sr. No.	Property	Raw rubber	Vulcanized rubber
1.	Tensile strength	200 kg/cm^2	2000 kg/cm^2
2.	Elongation at break	1200	800
3.	Rapidity of retraction	Good	Very good
4.	Water absorption	Large	Small
5.	Swelling in organic solvents	Infinite (soluble)	Large but limited
6.	Tackiness	Marked	Slight
7.	Useful temperature range	10 to 60°C	−40 to + 100°C
8.	Chemical resistance	Very poor	Much better
9.	Elasticity	Very high (300 to 1000%)	Low, depending on degree of vulcanization

4.10 APPLICATIONS OF RUBBER

Different varieties of rubbers have different applications in the manufacturing of following items.

(1) Due to its abrasion resistance, it is used for making bicycle, automobile and aeroplane tyres, shoe heads, conveyor belts, shock absorbers, automobile parts etc.

(2) Due to its elasticity, it is used for making rubber bands, mechanical rubber goods, golf balls, tubes for automobiles etc.

(3) Due to its chemical resistance, it is used for making rubber lined metal tanks and vessels used in chemical industry.

(4) Due to chemical resistivity to mineral oil petrol and some solvents etc., rubber hoses are used for their transmission.

(5) Due to electrical resistivity, it is used as insulating coating on wires and cables used for electrical power transmission and in electrician gloves.

(6) Polysulphide rubber is used as a "solid propellant fuel" for rocket motors.

(7) Rubber is used for making toys, sport goods, head bands for helmets and goggles etc.

(8) Sponge rubber is used for shock absorption, thermal insulation and sound insulation purposes.

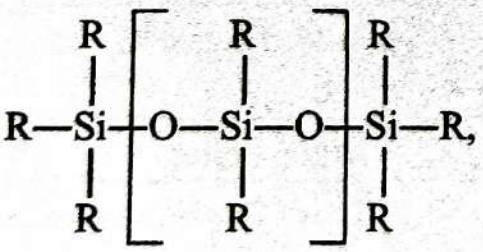
(9) It is used for making heart valves, transfusion tubings, paddling for plastic surgery etc.

(10) Rubber gaskets are used for sealing various types of equipment such as cooker, refrigerator doors, autoclaves etc.

.11 COMMERCIAL RUBBERS

(1) Silicone Rubbers:

Silicon resins contain alternate silicon oxygen structures which has organic radicals attached to silicon items.



where R= alkyl or phenyl radical

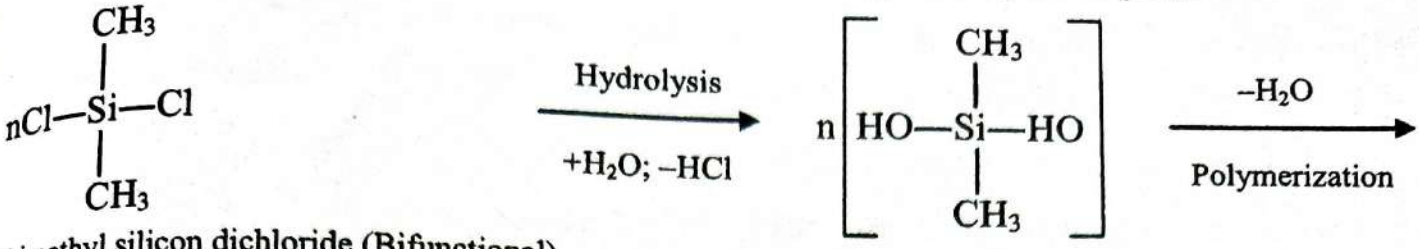
Preparation:

Silicon is reacted with alkyl halide. The reaction product is fractionally distilled to get ferent organosilicon chlorides.

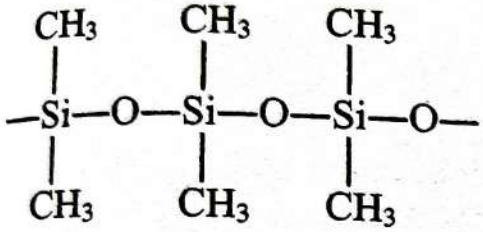
$$\underset{\text{(Methyl chloride)}}{CH_3Cl} + \underset{\text{(Silicon)}}{Si} \longrightarrow CH_3SiCl_3;\ (CH_3)_2Si\ Cl_2$$

Organosilicon halides are polymerized by careful controlled hydrolysis.

Dimethyl silicon dichloride is bifunctional and can give long chain polymers.

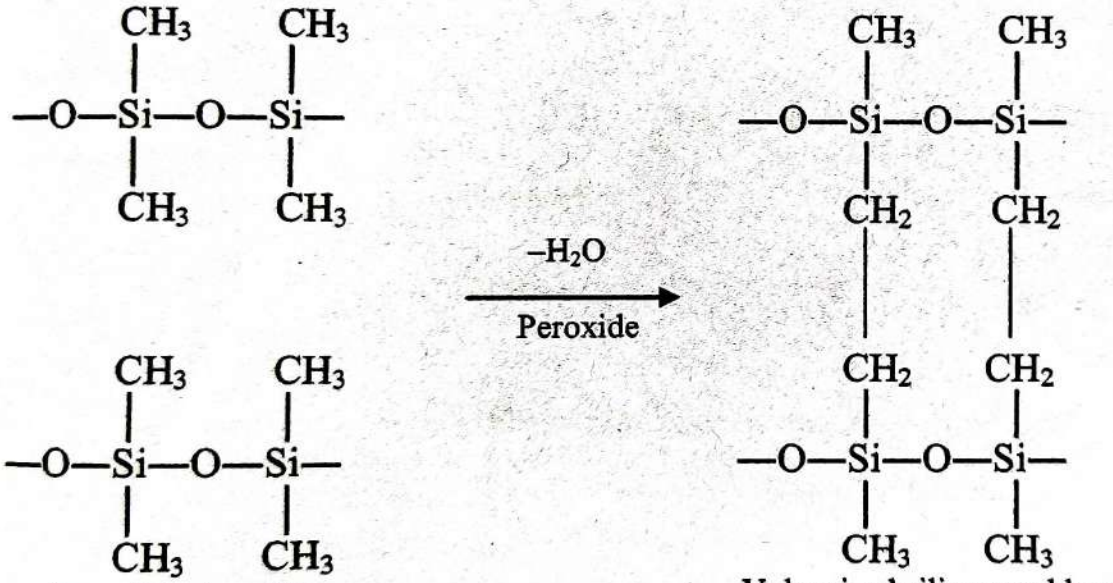


Dimethyl silicon dichloride (Bifunctional)



Dimethyl silicon polymer (silicon rubber)

Silicone rubbers can be vulcanized by using organic peroxides which cause the formation of cross-link between methyl groups of adjacent chains.



Raw silicone rubber

Vulcanized silicone rubber

Properties:

(1) They are stable to heat in the temperature range 50°C to 300°C.

(2) They are chemically inert.

(3) They posses electrical insulation.

(4) They posses water repellent character.

(5) They are abrasion resistant.

(6) They are resistant to ozone, U.V. light, solvents.

(7) They are costly.

(8) Their tensile strength can be increased by vulcanization.

Uses:

(a) As a sealing materials in search lights and in aircraft engines.

(b) For insulating the electrical wiring in ships.

(c) As an adhesive in electronics industry.

(d) For making artificial heart valves, transfusion tubing and padding for plastic surgery.

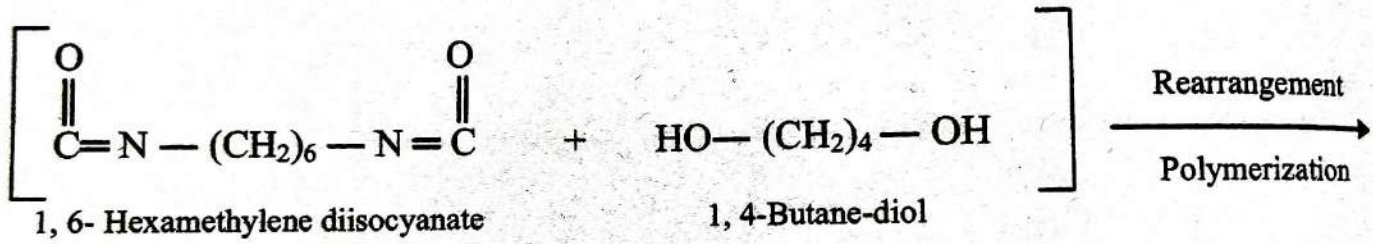
(e) For manufacture of tires for fighter aircrafts.

(2) Polyurethane Rubber:

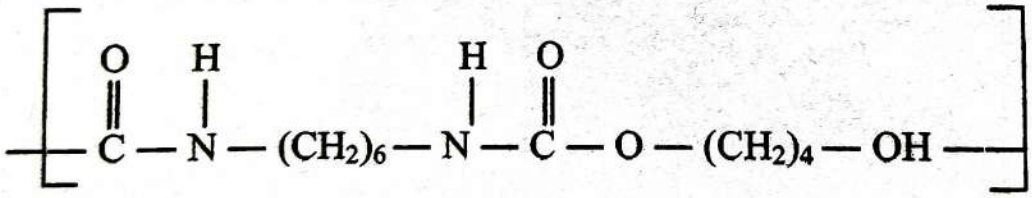
They contain urethane — NHCOO — linkage in their repeating units.

Preparation:

They are prepared by di-isocynate and a diol. Perlon-U is obtained by the reaction of 1, 4-butane diol with 1, 6-hexanediisocyanate.



1, 6- Hexamethylene diisocyanate 1, 4-Butane-diol



Polyurethane (Perlon-U)

Properties:

(i) Because of their saturated character, they are highly resistant to oxidation.

(ii) They are less stable at elevated temperatures.

(iii) They have good resistance to abrasion and organic solvents.

(iv) They are attacked by concentrated and hot acids and alkalis.

Uses:

(i) Used as substitute for leather.

(ii) Used to produce gaskets and seals.

(iii) Resilient polyurethane fibres are used for foundation garment and swim suits.

(iv) Used as adhesives, coatings, films, foams etc.

4.12 NUMERICALS

Problem 1: A polymer sample has a molecular weight of M = 2,00,000 g/mol and the repeat unit molecular weight is M_o = 200 g/mol. Calculate the degree of polymerization.

Solution:

$$\text{Degree of polymerization (DP)} = \frac{M}{M_o}$$

$$= \frac{200000}{200}$$

$$= 1000$$

Thus,

Degree of polymerization (DP) = 1000

Problem 2: The degree of polymerization of a polymer (DP) = 500. If molecular weight of it's repeat unit is M_o = 200 g/mol, determine the molecular weight of the polymer.

Solution:

$$M = DP \times M_o$$

$$= 500 \times 200$$

$$= 1,00,000$$

Thus,

Molecular Weight of Polymer = 1,00,000 g/mol

Problem 3: A polymer cube has a side length of 5 cm and mass of 500 g. Calculate the mass density of the polymer.

Solution:

$$\text{Volume} = \text{Side}^3 = 5^3 = 125 \text{ cm}^3$$

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

$$= \frac{500}{125}$$

$$= 4 \text{ g/cm}^3$$

Thus,

Density of Polymer = 4 g/cm^3

Problem 4: The density of a polymer is 1.5 g/cm^3. If a block of this polymer has a mass of 450 g, find its volume.

Solution:

$$\text{Volume} = \frac{\text{Mass}}{\text{Density}}$$

$$= \frac{450}{1.5}$$

$$= 300 \text{ cm}^3$$

Thus,

Volume of Polymer = 300 cm^3

Problem 5: A spherical polymer sample has a diameter of 8 cm and density of 0.90 g/cm^3. Calculate the mass of polymer sphere.

Solution:

$$\text{Radius R} = \frac{\text{Diameter}}{2}$$

$$= 4 \text{ cm}$$

$$\text{Volume} = \frac{4}{3} \times \pi \times r^3$$

$$= \frac{4}{3} \times \pi \times (4)^3$$

$$= \frac{4}{3} \times 3.14 \times 64$$

$$= 267.95 \text{ cm}^3$$

$$\text{Mass} = \text{Density} \times \text{Volume}$$

$$= 0.90 \times 268$$

$$= 241.15 \text{ g}$$

Thus,

Mass of Polymer Sphere = 241.15g

Problem 6: Polymer sample with cross sectional area of 10 mm^2. It withstands a maximum tensile force of 400 N before breaking. Calculate the tensile strength of the polymer.

Solution:

$10 \text{ mm}^2 = 10 \times 10^{-6} \text{ m}^2$

$$\text{Tensile Strength} = \frac{\text{Force}}{\text{Area}}$$

$$= \frac{400}{(10 \times 10^{-6})}$$

$$= 40 \text{ MPa}$$

Thus,

Tensile Strength of Polymer Sample = 40 MPa

Problem 7: The tensile strength of a polymer is 50 MPa. If the sample has a cross-sectional area of 10 mm^2, determine the maximum force it can withstand.

Solution:

$10 \text{ mm}^2 = 10 \times 10^{-6} \text{ m}^2$

Force = Tensile Strength × Cross-sectional Area

$= (50 \times 10^6) \times (10 \times 10^{-6})$

$= 500 \text{ N}$

Thus,

Maximum Force the sample can withstand = 500 N

4.13 REVIEW QUESTIONS

1. What are plasticizers? What are their functions?

Ans. Refer Section 4.3.

2. Write a note on fillers.

Ans. Refer Section 4.3.

3. What is meant by compounding of plastics? What are the different constituents of compounding? Write their uses.

Ans. Refer Section 4.3.

4. Give the classification of plastics

Ans. Refer Section 4.2.

5. Differentiate between thermosetting plastics and thermosoftening plastics.

Ans. Refer Section 4.2.

6. Which properties help to use plastics for common purposes?

Ans. Refer Section 4.1.

7. Give application of any two polymers, for industries.

Ans. Refer Section 4.5.

8. Describe the method of preparation, properties and application of polymethyl methacryalate (PMMA).

Ans. Refer Section 4.5.

9. Write a short note on elastomers.

Ans. Refer Section 4.6.

10. What is natural rubber? Explain the treatment of latex to get natural rubber.

Ans. Refer Section 4.7

11. Describe the drawbacks of natural rubber. How are they rectified?

Ans. Refer Section 4.8 and 4.9.

12. What is vulcanization of rubber? Mention its uses.

Ans. Refer Section 4.9.

13. Write a note on gutta percha.

Ans. Refer Section 4.7.1.

14. What is structural difference between cis and trans polyisoprenes?

Ans. Refer Section 4.7.2.

15. Differentiate between raw and vulcanized rubber.

Ans. Refer Section 4.9.

16. What is an elastomer? Give the basic reason behind elasticity of rubber.

Ans. Refer Section 4.6.

17. What is smoked rubber?

Ans. Refer Section 4.7 (b).

18. What is vulcanization of rubber? Give the structural change taking place in it.

Ans. Refer Section 4.9.

19. Give the applications of rubber.

Ans. Refer Section 4.10.

20. Describe the method of preparation, properties and application of polytetrafluoroethylene (PTFE).

Ans. Refer Section 4.5.

21. Describe the method of preparation, properties and application of polyurethane rubber.

Ans. Refer Section 4.11.

22. Describe the method of preparation, properties and application of silicone rubber.

Ans. Refer Section 4.11.

23. A polymer sample has a molecular weight of M = 3,00,000 g/mol and the repeat unit molecular weight is M_o = 150 g/mol. Calculate the degree of polymerization.

Ans. DP = 2000

24. The degree of polymerization of a polymer (DP) = 300. If molecular weight of its repeat unit is M_o = 100 g/mol, determine the molecular weight of the polymer.

Ans. Molecular Weight = 30000 g/mol

25. A polymer cube has a side length of 4 cm and mass of 640 g. Calculate the mass density of the polymer.

Ans. Density = 10 gm/cm^3

26. The density of a polymer is 2.0 g/cm^3. If a block of this polymer has a mass of 300 g, find its volume.

Ans. Volume = 150 cm^3

27. A spherical polymer sample has a diameter of 12 cm and density of 0.60 g/cm^3. Calculate the mass of polymer sphere.

Ans. Mass = 542.59 g.

28. Polymer sample with cross sectional area of 15 mm^2. It withstands a maximum tensile force of 300 N before breaking. Calculate the tensile strength of the polymer.

Ans. Tensile Strength = 20 MPa.

29. The tensile strength of a polymer is 40 MPa. If the sample has a cross-sectional area of 20 mm^2, determine the maximum force it can withstand.

Ans. Maximum Force sample can withstand = 800 N.

4.14 UNIVERSITY QUESTIONS

May 2008

1. Distinguish between thermoplastics and thermosetting plastics. (3 M)

Ans. Refer Section 4.2.

2. Write the preparation, properties and uses of PTFE. (3 M)

Ans. Refer Section 4.5.

December 2008

1. Explain preparation method and uses of PMMA. (7 M)

Ans. Refer Section 4.5.

May 2009

1. Explain preparation, properties and uses of PMMA. (3 M)

Ans. Refer Section 4.5.

2. What are the main constituents of plastics? Write the functions and examples of each constituent. (5 M)

Ans. Refer Section 4.3.

3. Write the preparation, properties and uses of silicone rubber. (3 M)

Ans. Refer Section 4.11.

December 2009

1. Distinguish between thermoplastics and thermosetting plastics. (3 M)

Ans. Refer Section 4.2.

2. Write the preparation, properties and uses of polyurethane rubber. (3 M)

Ans. Refer Section 4.11.

May 2010

1. Give synthesis properties and uses of PMMA and PTFE. (5 M)

Ans. Refer Section 4.5.

December 2010

1. Explain the following additives used for compounding of plastics:
   (i) plasticizers, (ii) resins, (iii) catalysts. (6 M)

Ans. Refer Section 4.3.

May 2011

1. Distinguish between thermoplastics and thermosetting plastics. (3 M)

Ans. Refer Section 4.2.

2. What are the main constituents of plastics? Write the functions and examples of each constituent. (5 M)

Ans. Refer Section 4.3.

3. Write the preparation, properties and uses of PMMA. (3 M)

Ans. Refer Section 4.5.

December 2011

1. Distinguish between thermoplastics and thermosetting plastics. (5 M)

Ans. Refer Section 4.2.

June 2012

1. What are the functions of fillers and plasticizers in the compounding of plastics? (4 M)

Ans. Refer Section 4.3.

2. Write preparation, properties and uses of Polymethyl Methacrylate (PMMA) and PTFE. (6 M)

Ans. Refer Section 4.5.

December 2012

1. Write synthesis, properties and applications of Kevlar. (3 M)

Ans. Refer Section 4.4.1.

2. Write the preparation, properties and uses of polyurethane rubber. (3 M)

Ans. Refer Section 4.11.

June 2013

1. What are plasticizers? Give its function. (3 M)

Ans. Refer Section 4.3.

2. Write preparation, properties and uses of Kevlar. (3 M)

Ans. Refer Section 4.4.1.

December 2013

1. What is the function of plasticiser in the compounding of plastic? Give two examples. (3 M)

Ans. Refer Section 4.3.

2. Distinguish between thrmoplastic and thermosetting resins. (3 M)

Ans. Refer Section 4.2.

3. Give the preparation, properties and uses of PMMA. (3 M)

Ans. Refer Section 4.5.

May 2014

1. Name the various ingredients in the compounding of plastics and give two examples of it. (3 M)

Ans. Refer Section 4.3.

2. What are thermoplastic polymers? Give two examples. Give the preparation, properties and uses of any one of it. (5 M)

Ans. Refer Section 4.2.

3. Give the preparation and uses of Kevlar. (2 M)

Ans. Refer Section 4.4.1.

December 2014

1. Explain the role of plasticizers and lubricants in the compounding of plastics. (3 M)

Ans. Refer Section 4.3.

2. Distinguish between thermoplastic and thermosetting resins. (3 M)

Ans. Refer Section 4.2.

3. Give the preparation, properties and uses of :

   (a) PMMA, (b) Kevlar. (6 M)

Ans. Refer Section 4.5 and 4.4.1.

May 2015

1. Explain compounding of plastics. (Five ingredients) (5 M)

Ans. Refer Section 4.3.

2. Give the preparation and applications of the following : (5 M)

   (a) PMMA, (b) PTFE.

Ans. Refer Section 4.5.

December 2015

1. Distinguish between thermoplastic and thermosetting resins. (3 M)

Ans. Refer Section 4.2.

2. Explain the functions of the following constituents in the compounding of plastics (any two) : (5 M)

   (a) Fillers, (b) Plasticizers, (c) Lubricants.

Ans. Refer Section 4.3.

3. Give the preparation, properties and uses of :

   (a) PMMA, (b) PTFE. (6 M)

Ans. Refer Section 4.5.

May 2016

1. Thermosetting polymers cannot be reshaped and reused. Give reasons. (3 M)

Ans. Refer Section 4.2.

2. Give the preparation, properties and uses of PMMA. (3 M)

Ans. Refer Section 4.5.

3. Explain the functions of the following constituents in the compounding of plastics. (any two) (5 M)

   (a) Plasticizers, (b) Lubricants, (c) Stabilizers

Ans. Refer Section 4.3.

December 2016

1. Distinguish between thrmoplastic and thermosetting resins. (3 M)

Ans. Refer Section 4.2.

2. What are functions of fillers and plasticizers in the compounding of plastics? (4 M)

Ans. Refer Section 4.3.

3. Write the properties, preparations and uses of PMMA. (3 M)

Ans. Refer Section 4.5.

June 2017

1. Give the preparation, properties and uses of PMMA. (3 M)

Ans. Refer Section 4.5.

2. What are the additives mixed with plastics for its compounding? Explain their functions. (4 M)

Ans. Refer Section 4.3.

3. Distinguish between thermoplastic and thermo setting plastic. (3 M)

Ans. Refer Section 4.2.

December 2017

1. Give the preparation, properties and uses of PMMA. (3 M)

Ans. Refer Section 4.5.

2. What are plasticizers? Give it's uses and examples. (3 M)

Ans. Refer Section 4.3.

3. Distinguish between thermoplastic and thermosetting plastics. (3 M)

Ans. Refer Section 4.2.

May 2018

1. Give the preparation, properties and uses of PTFE. (3 M)

Ans. Refer Section 4.5.

2. Discuss the following additives in compounding of plastics. (4 M)

   (i) Fillers

   (ii) Plasticizers.

Ans. Refer Section 4.3.

December 2018

1. Give the preparation, properties and uses of PMMA. (3 M)

Ans. Refer Section 4.5.

2. Distinguish between thermoplastic and thermosetting plastics. (3 M)

Ans. Refer Section 4.2.

May 2019

1. What is compounding of plastics? Explain the role played by various constituents used during compounding of plastics. (6 M)

Ans. Refer Section 4.3.

CHAPTER 5

ADVANCED POLYMERS

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5.1 Introduction to Advanced Polymers

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5.1 INTRODUCTION TO ADVANCED POLYMERS

Advanced polymers are high-performance materials that have superior mechanical, thermal, and chemical properties compared to conventional polymers. These materials are designed to meet the demands of aerospace, automotive, electronics, medical, and packaging industries, where durability, reliability, and performance are critical. Advanced polymers include a wide range of materials such as Liquid Crystal Polymers (LCPs), polyimides, fluoropolymers, conductive polymers, and biodegradable polymers.

Advanced polymers share most of the common properties. Some of these include the following: high mechanical strength, because they do not deform under a high level of stress and mechanical load; good thermal resistance because they can be applied at a high temperature, particularly in aerospace and automobile industries; good chemical stability because they do not corrode and degrade under aggressive chemicals and solvents. Some advanced polymers are electrically conductive and insulating by nature, which makes them worth the electronics industry. Most of the advanced polymers are light in weight; this guarantees a fuel efficiency of transportation industries.

Advanced polymers are applied very widely in the industries. It is used to make lightweight structures with low fuel consumptions but still has a good structure in aerospace industries. They are used in parts of the engine, fuel systems, and interiors to improve performance and safety in the automotive industry. Advanced polymers aid the electronics industry in flexible displays, sensors, and printed circuit boards. Biocompatibility is demanded by the medical field for implants, prosthetics, and drug delivery systems. Packaging uses advanced polymers in thin layers, such as films and coatings; it modifies the barrier properties in order to resist moisture, oxygen, and others for product damage.

Advanced polymers are versatile. They have become an important tool in developing innovative solutions in a variety of industries that contribute to technological advancements and sustainability efforts.

5.2 INTELLIGENT (SMART) POLYMERS

These are polymers that have the ability to change reversibly, based on the property, in response to external stimuli, such as temperature, pH changes, light, humidity, electric or magnetic fields, and other chemical environments. The aim is to make such materials "sense" their environment and respond accordingly. That makes them highly versatile for applications in medicine, biotechnology, environmental monitoring, electronics, and materials science.

Smart polymers belong to a class of stimuli-responsive materials. Their ability to change or adapt their structure in response to external stimuli allows for the possibility of making advanced materials characterized by dynamic and adjustable properties. Due to their internal adaptability, these materials can be used in any number of applications: drug delivery systems, self-healing materials, adaptive coatings.

5.2.1 Types of Smart Polymers

1. Thermoresponsive Polymers: Thermoresponsive polymers change their shape or solubility in response to a change in temperature. Probably one of the most typical

representatives is poly(N-isopropylacrylamide), where a sharp transition between the states hydrophilic and hydrophobic is achieved at the lower critical solution temperature, which is about 32°C. At temperatures below that for the LCST, the polymer is water soluble; at temps high above the LCST temperature, the polymer insolubility in water indicates there was a phase transition during temperature upswing from swollenhydrated-to collapsed-dehydrated state.

Usages:

Drug delivery systems are designed such that the polymer can administer medications at a designated body temperature.

Temperature-sensitive hydrogels for tissue engineering.

The controlled release of agrochemicals related to temperature fluctuations.

2. pH-Responsive Polymers: pH-responsive polymers are responsive and change their structure or solubility in the presence of different pH environments. They depend on the pH-level environment in which they change. Such polymers incorporate weakly acidic or bases that can protonate or deprotonate at each pH. For example, poly (acrylic acid), which gels or changes over solubility in changed pH environments.

Utilizations:

Targeting a specific region in the body such as acidic environment of the tumor or stomach using drug delivery systems: pH-sensitive polymers.

Environmental monitoring: Determination of pH variation in soil, water, or industrial processes.

Tissue scaffolds and biosensors.

3. Photoresponsive Polymers (Light-Responsive Polymers): The physical properties of these responsive polymers change in the presence of specific wavelengths of light, often ultraviolet or visible radiation. One of the most studied examples includes azobenzene-based polymers. Azobenzene units undergo a reversible isomerization transition from trans to cis when exposed to UV radiation and lead to changes in the shape or mechanical properties of the material.

Usage:

Photoreversible drug delivery: Controlled drug release through the help of light may be provoked for targeted therapy in different body parts.

Smart coatings: Coatings that change colour or properties when exposed to light.

Photo-actuators in robotics and nanotechnology.

4. Electrically Responding Polymers: It responds to an electric field or current. Most familiar examples include EAP, which change in shape or shape dimension in response to applied voltage. The majority of ionic types and the acting sensors can

perform different tasks related to electrochemistry; for example, an appropriately researched case is conductive polypyrrole and how its shape is able to be altered due to an applied electric current.

Consumption:

Actuators for robotics, prosthetics, and artificial muscles.

Sensors in electronic devices.

Electrochromic devices for smart windows and displays.

These are polymers that react to a magnetic field. Normally, they will contain some kind of magnetic nanoparticles, like iron oxide, that make it possible to remotely control the material by applying an external magnetic effect. Such polymers could reversibly change shape, heal themselves, or respond by releasing contained pharmaceuticals or chemical substances.

Usages:

Targeted drug delivery: Magnetic fields can direct the polymer to specific sites in the body, releasing drugs at precise locations.

Self-healing materials where the magnetic field triggers the polymer to reconfigure and restore its original shape.

5. Humidity-Sensitive Polymers: These polymers change their properties in response to a change in moisture or humidity. An example is Poly (vinyl alcohol) PVA, which can absorb water and swell when the levels of humidity increase.

Applications:

Moisture responsive sensors in packaging to detect spoilage.

Smart textiles and clothing that change their properties in response to changing moisture contents.

Environmental monitoring devices.

Mechanisms of Smart Polymer Behaviour

Intelligent polymers work based on interaction between their chemical composition and external stimulations. Such processes in which these polymers go through transitions are:

H-bonding: These polymers usually have hydrophilic groups that exhibit considerable potential for forming hydrogen-bonding with water. The degree of hydration would be affected due to changing swelling or solubility.

Ionic interactions: Ionic interactions between the charged moieties in the polymer framework are critical in pH- or electrically responsive polymers for the reaction of the material to an external stimulus.

Cross-linking: Some intelligent polymers show cross-linked structures which are sensitive to expand or contract when there is an external stimulus and this leads to substantial changes in volume or shape.

Crystallization of polymer: The temperature or photoirradiation can cause crystallization or phase transitions for thermoresponsive and photoresponsive polymers, and this affects the material properties further.

5.2.2 Applications of Smart Polymers

1. Biomedical Applications:

Drug Delivery: Intelligent polymers are employed to develop delivery systems that release pharmaceuticals in reaction to physiological parameters (for instance, pH levels and temperature variations). This approach facilitates targeted and regulated drug administration, thereby minimizing adverse effects and enhancing therapeutic effectiveness.

Tissue Engineering: Using scaffolds that can modify shapes or properties in reaction to environmental signals, thus initiating and promoting cell growth for subsequent tissue regeneration.

Wound Healing: The intelligent polymers can be used in dressings that sense changes in the environment of the wound, for example, pH or temperature, for faster healing.

2. Environmental and Energy Applications:

Pollution Control: pH-responsive and temperature-sensitive polymers can be used in filters that remove pollutants or contaminants from water or air, responding dynamically to changes in environmental conditions.

Energy Harvesting: Certain smart polymers can morph under mechanical stimuli, providing an opportunity for energy harvesting in flexible sensors or generators.

3. Intelligent Coatings and Interfaces:

Self-Healing Materials: Research into polymers that can "self-heal" upon encountering mechanical stress or environmental damage is an increasingly large field of study. Such materials may have great application in the aerospace, automotive, and electronics industries, among others.

Anti-fouling Coatings Polymers that are sensitive to changes in environmental conditions (for example, water salinity or temperature) can be employed in coatings that prevent marine biofouling.

4. Sensors and Actuators:

Smart Textiles: Polymers that are sensitive to temperature, pressure, or light can be added to clothes to make smart clothes. These clothes adjust to changing environments, hence making comfortable clothing for all climates.

Robotic Actuators: Polymers that are sensitive to an applied electrical or magnetic field and can change their shape or stiffness, making them interesting for soft robotics, offer more flexible and adaptive robotic components.

5.3 BIO-POLYMERS

Biopolymers are naturally occurring long chain molecules which are involved in biological changes important for our lives. These polymers are present in living matter, in both animals and plants.

5.3.1 Types of Bio-Polymers

Broadly speaking, they are of four types:

(A) Carbohydrates: They are polyhydroxy aldehydes/ketones or compounds that can be hydrolyzed to them. They are a group of compounds represented by the general formula $C_x (H_2O)_y$. Carbohydrates are further divided into:

(i) **Monosaccharides:** They are the simplest carbohydrates containing three to seven carbon items. They cannot be hydrolyzed to smaller molecules. For example, Glucose, Fructose.

(ii) **Oligosaccharides:** On hydrolysis, they give two to nine monosaccharides molecules. For example, Maltose, Sucrose.

(iii) **Polysaccharides:** They are the ones in which monosaccharides form the structural monomeric units. For example, Starch, Cellulose.

Functions of Carbohydrates:

1. They are the main source of our food.
2. Cellulose present in grass and plants act as food for various grazing animals.
3. They provide us clothing in the form of cotton, linen, cellulose and rayon.
4. They provide us shelter. Cellulose in the form of wood is used to build houses.
5. They form structural components of cells.
6. They provide energy for the functioning of the living system. In the living organism, polysaccharides undergo hydrolysis to yield glucose. Slow oxidation of glucose provides energy.

(B) Proteins: They are complex nitrogenous organic compounds of high molecular masses. They are synthesized by plants and animals, which on hydrolysis yield

amino acids. Proteins are polymeric amides, composed of long chains amino acids, linked by peptide bonds. Twenty different ammino acids are found in proteins.

There are two broad classes of proteins:

(i) **Fibrous proteins:** These molecules are linear and tend to lie side by side to form fibres. There are strong intermolecular forces between them. They are insoluble in water. They serve as the main structural material of animal tissues as keratin, collagen, myosin, fibroin.

(ii) **Globular proteins:** The molecules of globular proteins are folded into spheroidal shapes where the lipophilic parts are turned inward and hydrophilic parts are turned outward. They have intramolecular hydrogen bonding. They are soluble in water and aqueous solutions of acids, bases. They are essential for the maintenance and regulation of the life processes. They exist in hemoglobin, fibrinogen, antibodies, enzymes.

Functions of Proteins:

1. They serve as the structural components of the living organisms.
2. They yield energy.
3. They serve as enzymes which catalyze bio-chemical reactions.
4. They help in the formation of hemoglobin, chromosomes.
5. They form hormones and antibodies.
6. They take part in genetics.
7. They help in regulation of metabolism.

(C) **Nucleic Acids:** Nucleic acids are high polymers of nucleotide consisting of a sugar, a phosphate group and a nitrogen based residue. It consists of three parts (i) Nitrogen containing base, (ii) Pentose sugar, (iii) Phosphate group.

Types of nucleic acids:

There are two types of nucleic acid depending upon the type of sugar residue.

1) **DNA (Deoxyribo Nucleic Acid) :** It is a poly nucleotide consisting of deoxyribose (a pentose) as the sugar and guanine, cystosine, adenine or thymine as the base in its structure. It is responsible for the inheritance of genetic character of a particular species of a living cell.

2) **RNA (Ribo Nucleic Acid) :** It is formed in the nucleus and it is found in the cytoplasm of the cell. There are three types of ribo nucleic acids.

a) **Messenger-RNA (m-RNA):** It is produced by the DNA. It is single-stranded and constitutes about 15% of the total RNA.

m-RNA carries the genetic information (code) from DNA to the ribosomes where protein is synthesized.

b) **Riosomal-RNA (r-RNA):** It is found in the ribosomes. It is synthesized in the nucleus by DNA. It is associated with proteins to form the ribosomes. It is metabolically stable. It is single-stranded comprising of 80% of total RNA.

r-RNA forms the site for proteins synthesis. It is supposed to help the binding of m-RNA to the ribosomes during the protein synthesis.

c) **Transfer-RNA (t-RNA):** The other name of the t-RNA is soluble-RNA. It is synthesized in the nucleus by the DNA. It is single-stranded and has very short life. There are twenty different types of t-RNA and constitutes about 5% of total RNA.

t-RNA carries amino acids from different parts of cytoplasm to the ribosomes during protein synthesis (carriers of amino acids).

(D) Lipids: They are defined as a heterogeneous group of naturally occurring substances of the higher fatty acids, and are essential constituent of all plants and animal cells. They are composed of carbon, hydrogen, oxygen, and in some cases even nitrogen and phosphorous. They may be classified as fats and oils, phospholipids, glycolipids, steroids and waxes.

Functions of Lipids:

1. They are structural components of cell membrane.
2. Due to high energy content, they serve as the energy reservoir of the body.
3. They act as protective coating on the surface of organs.
4. They facilitate the absorption of the fat-soluble vitamins.
5. They serve as heat-insulators and shock absorbers in the tissues of animals.

5.4 CONDUCTING POLYMERS

Most of the polymeric materials are poor conductor of electricity due to unavailability of large number of free electrons. In past several years, polymeric materials have been synthesized possessing electrical conductivities on par with metallic conductors. Organic polymers with highly delocalized π-electron system having electrical conductance of the order of conductors are called conducting polymers. The basic requirement for them is the formation of continuous conjugation through the polymer chain.

Table 5.1 : Electrical conductivity of some polymers

Polymers	Electrical conductivity ($ohm^{-1}\ m^{-1}$)
Phenol formaldehyde	10^{-9}-10^{-10}
Polymethyl methacrylate	$<10^{-12}$
Nylon 6,6	10^{-12}-10^{-13}
Polystyrene	$<10^{-14}$
Polyethylene	10^{-15}-10^{-17}
Polytetrafluro ethylene	$<10^{-17}$

5.4.1 Types of Conducting Polymers

Different types of conducting polymers are as follows:

(i) **Intrinsically conducting polymers:** It is a polymer whose backbone or associated groups consists of delocalized electron pair or residual charge. In an electric field, conjugated π-electron of the polymer gets excited, and hence can be transported through the solid polymeric materials. Overlapping of orbitals over the entire backbone results in the formation of valance bands as well as conduction bands. Some common examples are polyacetylene polymers, polyaniline, polyanthrylene, polypyrrole, polythiophene, polyazomethine etc.

(ii) **Extrinsically conducting polymers:** It is a polymer whose conductivity is due to the presence of externally added ingredient in them. They are of two types:

(a) **Conductive elements-filled polymers:** It is a resin filled with conducting elements such as carbon black or metal oxides, in which the polymer acts as a binder to hold the conducting elements. Along with conductivity, these polymers are low in cost, light in weight, mechanically durable and strong.

(b) **Blended conducting polymer:** It is a polymer obtained by blending a conventional polymer with conducting polymer. Such polymers possess better physical, chemical and mechanical properties.

(iii) **Doped conducting polymers:** It is obtained by exposing a polymer to a charged transfer agent either in gas phase or in solution phase. The conductivity of Intrinsically Conducting Polymers (ICP) can be increased by creating either positive or negative charges on the polymer backbone by oxidation or reduction known as doping. It is of two types:

(a) P-doping: In this, an Intrinsically Conducting Polymer (ICP) is treated with a Lewis acid where oxidation process takes place and positive charges on the polymer backbone are created. Commonly used p-dopants are I_2, Br_2, AsF_5, PF_6, naphthylamine, etc.

$$(C_2H_2)_n + 2FeCl_3 \rightarrow (C_2H_2)_n^{+} FeCl_4^{-} + FeCl_2$$

$$2(C_2H_2)_n + 3I_2 \rightarrow 2[(C_2H_2)_n^{+} I_3^{-}$$

(b) N-doping: In this, an Intrinsically Conducting Polymer (ICP) is treated with a Lewis base where reduction takes place and negative charges are created on the polymer backbone. Commonly used n-dopants are Lithium (Li), Sodium (Na), Calcium (Ca) etc.

$$\ldots\text{–CH = CH – CH = CH – } \ldots + B \xrightarrow{\text{Reduction}} \ldots - CH = CH - \overline{C}H = \underset{\displaystyle B^{+}}{\underset{|}{CH}} - \ldots$$

(Lewis Base)

(iv) Co-ordination conducting polymer: It is a charge transfer complex containing polymer obtained by combining a metal atom with a poly dentate ligand.

5.4.2 Applications of Conducting Polymers

(i) In rechargeable light weight batteries based on perchlorate doped polyacetylene-lithium system. These are about 10 times lighter than conventional lead storage batteries.

(ii) In wiring in aircrafts and aerospace components.

(iii) In electronic devices such as transistors and diodes and in telecommunication systems.

(iv) In antistatic coating for clothing.

(v) In electromagnetic screening materials.

(vi) In photovoltaic devices.

(vii) In molecular wires and molecular switches.

5.5 LIQUID CRYSTAL POLYMERS (LCP)

It would be basic to know what a liquid crystal is before one gets to know the LCPs. A liquid crystal is one of those phases of matter where the properties of liquid and that of a solid crystal are reflected simultaneously. Normal liquids do not show molecular ordering which is the signature of a solid; however they can flow, which is an essential property.

In LCPs, liquid crystalline phases are exhibited by the rigid rod-like molecular structures known as mesogens. The mesogen arrangement gives rise to an orderly pattern to produce ordered phases even during the molten state. This ordered arrangement also explains why LCPs have better properties such as high strength, thermal resistance, and chemical stability. Liquid Crystal Polymer is a unique class of thermoplastic materials that exhibits properties of both liquid crystals and polymers. In these materials, ordered molecular structures are retained both in the solid and molten states. LCPs have excellent mechanical, thermal, and chemical properties. They are useful in a large number of high-performance applications. This behavior is unique due to the LCPs, since their molecules align and keep a well-ordered condition even when at molten state unlike general polymers.

There are two types of LCPs based on their behaviour.

1. Thermotropic LCPs:

These LCPs are thermotropic which exhibit liquid crystalline phases when heated.

These are used more for high temperature applications such as electronic components and automobile parts.

2. Lyotropic LCPs:

These LCPs are lyotropic, which forms liquid crystalline phases once it dissolves into a solvent. They are mainly used to produce strong tensile strength fibres, such as Kevlar.

5.5.1 Properties of Liquid Crystal Polymers

Properties of Liquid Crystal Polymers are as follows:

1. Heat Resistance:

This is one of the most exceptional properties of LCPs-that they can withstand such high temperatures that do not deteriorate them at all. These polymers have the ability to withstand temperatures at 300°C or even greater, depending upon the formulation applied. This one property positions them at the forefront for potential applications in materials which, after exposure to very high temperatures, with material performance required to withstand automotive engine component performance through electronic devices and industrial machineries. Most other polymers will soften or degrade with rise in temperature, whereas LCPs maintain their structure integrity and performance through long-term durable harsh environments.

2. Chemical Resistance:

Such polymers also provide excellent resistance towards a wide array of chemicals. Chemical resistances include acids, bases, solvents, and oxidizing agents. Thus, they are used in applications with an acute presence of aggressive chemicals. Such applications

are those in the chemical processing industry, medical device applications, and in automotive parts. They also exhibit resistance to prevent corrosion and degradation or any form of loss in their mechanical properties and hence expand service life for LCP-based component parts.

3. High Strength and Stiffness:

They are lightweight but have the highest strength along with stiffness for thin-wall parts as well as components. The ability of the structure of molecules in LCP to be at high values for maintaining mechanical strength makes them fit parts designed for carrying strains and stresses with load bearing. For example, LCP prepared connector and sockets for electronics which such parts were allowed to undergo multiple insertion and removal without developing signs of deformity or fractures due to their relatively stiff nature so resisting bending, and warping; thus achieving stable form even after longtime passage.

4. Low Moisture Absorption:

LCPs have low absorption rates of moisture. This means that they do not absorb water or humidity from the environment. Such an aspect is particularly significant in applications under damp or humid conditions, where other materials might swell, degrade, or lose their mechanical properties. In contrast, LCPs maintain performance characteristics and thus enable reliable operation in outdoor electronics, automotive parts, and medical devices exposed to bodily fluids.

5. Electrical Insulation:

The LCPs exhibit good dielectric characteristics and, thus, can be applied as electrical insulation materials in a number of electronic applications. It successfully resists the electric current flow; thus, there is no short circuitting in the electronic components. This is an assurance of the safe and reliable component. LCPs are also widely employed in PCBs, connectors, and other electrical components demanding high insulation performance. Their stability over a wide range of temperatures and frequencies will further increase their suitability for advanced electronics.

6. Low Thermal Expansion:

LCPs have low thermal expansion and therefore they can maintain the same size and shape at a broad range of temperatures. This property is very important for applications where the material is to be heated and cooled repeatedly during its life cycle, such as in electronic components and automotive components. Low thermal expansion gives the LCP components minimal change in shape while exposed to changing temperatures and high reliability with life expectancy. This stability also offers high levels of accuracy in the case of parts machined with small tolerances or precision.

7. Flame Resistance:

This material is intrinsically flame-resistant, and no such additives are required to add them to ultra-high fire resistance standards. This feature is very important for industries whereby fire safety needs to be highly emphasized, for instance, in aerospace, automotive, and electronics. LCPs does not catch fire and therefore does not produce toxic fumes with the support of open flames. Therefore, these materials can be safely used in the fire-prone areas. The flame retardance also satisfies the safety requirements that have been the strictest of any industry.

5.5.2 Applications of Liquid Crystal Polymers

Applications of Liquid Crystal Polymers are as follows:

1. **Electronics** – Used in connectors, circuit boards, and flexible displays due to electrical insulation property and precision moulding.
2. **Aerospace and Automotive** – Sensors, fuel systems, and under-the-hood parts, as they are lightweight and have a high temperature.
3. **Medical Devices** – Surgical tools, implants, drug delivery units because of biocompatibility and resistance to sterilization.
4. **Industrial** – Pump, valve, and seal applications with extreme chemical conditions.

LCPs are valued for performance in high-temperature, high-stress applications with dimensional stability and mechanical integrity.

5.6 REVIEW QUESTIONS

1. Write an informative note on smart polymers.

Ans. Refer Section 5.2.

2. Explain the term intelligent polymers.

Ans. Refer Section 5.2.

3. Give the different types of intelligent polymers.

Ans. Refer Section 5.2.1.

4. Explain the applications of smart polymers.

Ans. Refer Section 5.2.2.

5. Write an informative note on Bio-polymers.

Ans. Refer Section 5.3.

6. What is Bio-polymers?

Ans. Refer Section 5.3.

7. Explain the different types of Bio-polymers.

Ans. Refer Section 5.3.1.

8. Write a brief note on carbohydrates.

Ans. Refer Section 5.3.1 (A).

9. Write a short note on proteins.

Ans. Refer Section 5.3.1 (B).

10. Write a short note on Lipids.

Ans. Refer Section 5.3.1 (D).

11. Write a short note on Nucleic acid.

Ans. Refer Section 5.3.1 (C).

12. What are advanced polymers?

Ans. Refer Section 5.1.

13. Write a note liquid crystal polymer.

Ans. Refer Section 5.5.

14. Explain the properties of liquid crystal polymers.

Ans. Refer Section 5.5.1.

15. Give the applications of Liquid crystal polymers.

Ans. Refer Section 5.5.2.

CHAPTER 6

NANOMATERIALS

CONTENTS

6.1 Introduction
6.2 Graphite
6.3 Graphene
6.4 Fullerenes
6.5 Carbon Nanotubes
6.6 Applications of Nanomaterials
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6.1 INTRODUCTION

What is Nanotechnology?

Until very recent times, the general procedure utilized by scientists to understand the chemistry and physics of materials has been to begin by studying large and complex structures and then to investigate the fundamental building blocks of these structures that are smaller and simpler. This approach is sometimes termed "top-down" science. However, with the advent of scanning probe microscopes, which permit observation of individual atoms and molecules, it has become possible to manipulate and move atoms and molecules to form new structures and thus design new materials that are built from simple atomic level constituents. This ability to carefully arrange atoms provides opportunities to develop mechanical, electrical, magnetic and other properties that are not otherwise possible. We call this the "bottom-up" approach and the study of the properties of these materials is termed as nanotechnology.

Good things come in small packages the unique properties of nanomaterials and structures on the nanometer scale have sparkled the attention of material developers. Incremental shifts in product performance using these materials, for example, as fillers in plastics, as coatings on surfaces and as UV protectants in cosmetics are already occurring. The technology holds more promise for the future though and is expected to bring more disruptive changes to both products and markets.

What are Nanomaterials?

Nano, a prefix denoting a factor of 10^{-9} has its origin in the Greek nanos meaning dwarf. Nanomaterials (nanocrystalline materials) are materials possessing grain sizes on the order of a billionth of a meter. They manifest extremely fascinating and useful properties, which can be exploited for a variety of structural and non-structural applications. Nanomaterials research literally exploded in mid-1980s in the U.S. All the scientists and technologists were inspired to venture into uncharted nanoterrain to do something big with something very small.

All materials are composed of grains which in turn comprise many atoms. These grains which are usually invisible to the naked eye, depending on their size. Conventional materials have grains varying in size anywhere from 100s of microns (μm) to millimeters (mm). A micron (μm) is a micrometer or a millionth (10^{-6}) of a meter. An average human hair is about 100 μm in diameter. A nanometer (nm) is even smaller a dimension than a μm and is a billionth (10^{-9}) of a meter. A nanocrystalline material has grains on the order of 1-100 nm i.e. particles with a size between 1 to 100 nm are normally regarded as nanomaterials. The average size of an atom is on the order of 1 to 2 angstorms (Å) in radius. 1 nanometer comprises 10 Å, and hence in one nm there may be 3-5 atoms, depending on the atomic radii.

Fig. 6.1 shows the size of nanoparticles in comparison with other small particles.

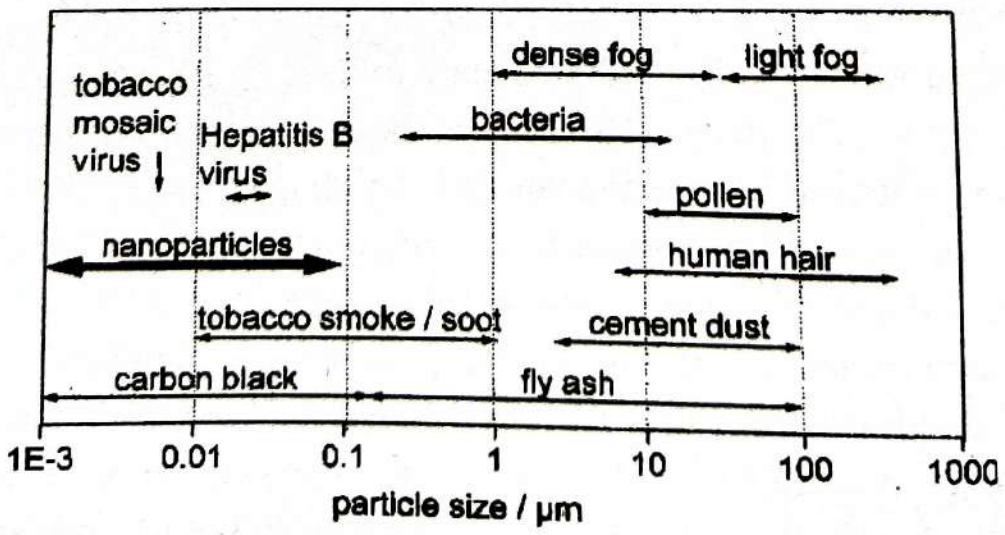

Fig. 6.1 : Typical size of small particles.

The regime below 0.1 μm corresponds to the dimension of nanoparticles

In general, nanomaterials may have globular, plate-like, rod-like or more complex geometries. Near spherical particles which are smaller than 10 nm are typically called clusters. The number of atoms in a clusters increases greatly with its diameter as explained in **Fig. 6.2** for sodium cluster.

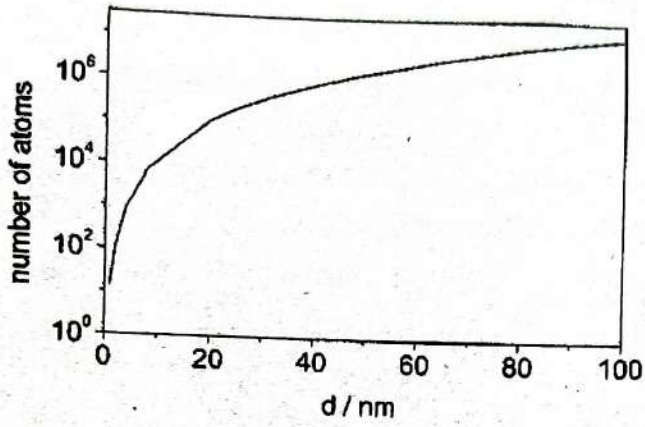

Fig. 6.2 : Number of sodium atoms in a spherical cluster of diameter d

There are 13 atoms in a cluster at 1 nm diameter and at 100 nm diameter the clusters can accommodate more than 10^7 atoms. Clusters may have a symmetrical structure which is different in symmetry from that of the bulk. They may also have an irregular or amorphorous shape.

It is below a dimension of 100nm where properties such as melting point, colour (i.e. band gap and wavelength of optical transitions), ionization, potential, hardness, catalytic activity and selectivity, magnetic properties such as coercivity, permeability and saturation magnetization which we generally think of as constant vary with size.

The properties of materials can be different at the nanoscale for two main reasons :

(i) Increased relative surface area.

(ii) Quantum effects.

Nanoparticles exhibit a number of special properties relative to bulk material. Copper nanoparticles smaller than 50 nm are considered superhard materials that do not exhibit the same malleability and ductility as bulk copper. The change in property is always not desirable. Ferroelectric materials smaller than 10nm can switch there magnetization direction using room temperature thermal energy, thus making them useless for memory storage. Suspensions of nanoparticles are possible because the interaction of the particle surface with solvent is strong enough to overcome differences in density which usually result in material either sinking or floating in a liquid. Nanoparticles often have unexpected visible properties as they are small enough to confine their electrons and produce quantum effects. For example, gold nanoparticles appear deep red to black in solution. Nanoparticles have very high surface area to volume ratio. This provides tremendous driving force for diffusion at elevated temperatures.

Nanocrystalline materials are exceptionally strong, hard, ductile at high temperatures, wear resistant, erosion resistant, corrosion resistant and chemically very active. These

nanomaterials are also much more formable than their conventional commercially available counterparts.

6.2 GRAPHITE

Graphite is another polymorph of carbon having a crystal structure. It is different from that of diamond and is more stable than diamond at ambient temperature and pressure. It is composed of layers of hexagonally arranged carbon atoms within the layers each carbon atom is bonded to three co-planar neighbour atoms by strong covalent bonds. The fourth bonding electron participates in a weak Van der Waal type of bond between the layers. Due to these weak interplanar bonds, interplanar cleavage is facile giving rise to the excellent lubricative properties of graphite. The electrical conductivity is relatively high in crystallographic directions parallel to the hexagonal shape. Graphite has high strength and good chemical stability at elevated temperatures and in non-oxidizing atmosphere, high thermal conductivity, low co-efficient of thermal expansion and high resistance to thermal shock. It shows high adsorption of gases and good machineability.

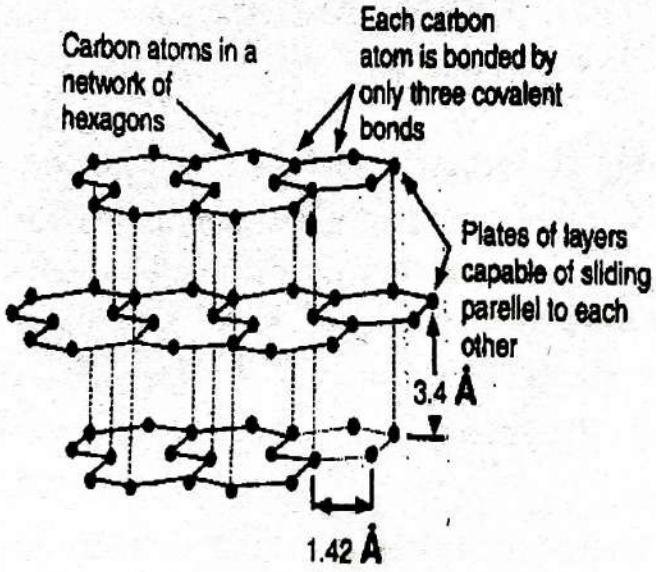
Carbon atoms in a network of hexagons
Each carbon atom is bonded by only three covalent bonds
Plates of layers capable of sliding parellel to each other
3.4 Å
1.42 Å

Fig. 6.3 : The Structure of Graphite

Applications :

(i) It is used as heating element for electric furnaces, high temperature refractories and insulations in chemical reactor vessels.

(ii) It can be used as electrodes for arc welding, in metallurgical crucibles, in casting moulds for metal alloys and ceramics.

(iii) It is used for electrical contact, brushes and resisters.

(iv) It can be used as electrodes in batteries and in air purification devices.

6.3 GRAPHENE

Graphene is an interesting material due to its incredible properties in terms of strength, flexibility, conductivity, and transparency. It was first isolated by physicists

Andre Geim and Konstantin Novoselov in 2004. It is a one-atomic layer of carbon atoms arranged in a two-dimensional honeycomb lattice. It is the basic structural unit of other carbon allotropes, like graphite, carbon nanotubes, and fullerenes. Despite having a thickness of only one atom, it is very strong, lightweight, and possesses extraordinary electrical properties and thermal conductivity.

In short, graphene is a thin, transparent sheet composed of carbon atoms, where every carbon atom is bonded to its neighbouring carbon atoms in a hexagonal manner.

Properties:

1. **High Strength**

Graphene is one of the strongest known materials. It is 200 times stronger than steel, which makes it highly durable and can withstand extreme forces.

2. **Flexibility and Elasticity**

Graphene is extremely flexible. It can be bent, stretched, or twisted without breaking. It can stretch up as much as 20% of its original length.

3. **Electrical Conductivity**

Graphene is a very good conductor of electricity. Since electrons can pass through with little resistance, it is most useful for manufacturing of electronic devices.

4. **Thermal Conductivity**

Graphene possesses excellent thermal conductivity as it can transfer heat very well. This makes it useful in applications that require efficient heat dissipation.

5. **Transparency**

Graphene is almost completely transparent, absorbing only about 2.3% of visible light. This makes it useful for applications like transparent touch screens and solar cells.

6. **Impermeability**

Graphene is highly impermeable, which makes it suitable material for protective coatings.

7. **Chemical Stability**

Graphene is chemically stable and resistant to corrosion. Therefore, it can be used in harsh environments.

Applications:

1. **Electronics and Semiconductor Industry**

Graphene transistors replaced traditional silicon-based transistors, which helped in developing faster and efficient computing devices. Thus, the flexible and transparent electronics made with graphene could revolutionize mobile devices, TVs etc.

2. **Energy Sector**

Graphene could increase the efficiency of solar panels and energy storage devices, thus lowering the energy costs. Graphene-based supercapacitors could replace traditional batteries with faster charging and long-lasting energy solutions.

3. Medical and Healthcare Sector

Graphene is applied in medical devices and implants. Its biocompatibility and antimicrobial properties make it suitable for drug delivery, wound healing, and cancer therapy.

4. Aerospace and Automotive Industry

Graphene-enhanced materials reduce the weight of vehicles and aircraft, leading to improved fuel efficiency and performance.

5. Environmental Applications

Membranes made from graphene are used in water purification and desalination. Graphene also helps in air pollution control by capturing harmful gases and particles.

6. Defense and Military

Strength and flexibility of graphene makes it suitable for body-armour and bullet-proof materials.

6.4 FULLERENES

Another polymorphic form of carbon was discovered in 1985. It exits in discrete molecular form and consists of a hollow spherical cluster of 60 carbon atoms; a single molecule is denoted by C_{60}. Each molecule is composed of groups of carbon atoms that are bonded to one another to form both hexagon (6 carbon atoms) and pentagon (5 carbon atom) geometrical configuration. One such molecule shown in **Fig. 6.4** is found to consists of 20 hexagons and 12 pentagons which are arrayed such that no two pentagon share a common side; the molecular surface thus exhibit the symmetry of a saucer ball. The material composed of C_{60} molecules is known as buckminsterfullerene, named in honor of R. Buckminster Fuller, who invented the geodesic dome. Each C_{60} is simply a molecular replica of such a dome. NMR spectrum of C_{60} reveals a single line. Buckminster fullerene is found as a byproduct of soot formation.

Since that time, the family of fullerenes (closed spherical carbon structures) increased, and now it consists of C_{70}, C_{76}, C_{84}, C_{240}, C_{540} and so on. In 1996, their discovery won a Nobel prize in chemistry. They are a class of closed cage carbon molecule C_n characteristically containing 12 pentagons and a variable number of hexagons. Hexagons $= \dfrac{\text{Number of carbon atoms} - 20}{2}$.

Fullerenes composed of less than 300 carbon atoms, or endohedral fullerene are commonly known as "buckyballs". Giant fullerenes or fullerenes with more than 300 carbon atoms include single shelled or multishelled carbon structures, onions and nanotubes.

Fullerenes are the third allotropic form of carbon material after graphite and diamond. Diamond and graphite may be termed as network solids, in that all the carbon atoms form primary bonds with adjacent atoms throughout the entirety of the solid. The carbon atoms

in buckminster fullerene bond together to form these spherical molecules. In the solid state the C_{60} units form a crystalline structure and pack together in a face-centered cubic array. As a pure crystalline solid, this material is electrically insulating. However, with proper impurity additions, it can be made highly conductive and semi-conductive.

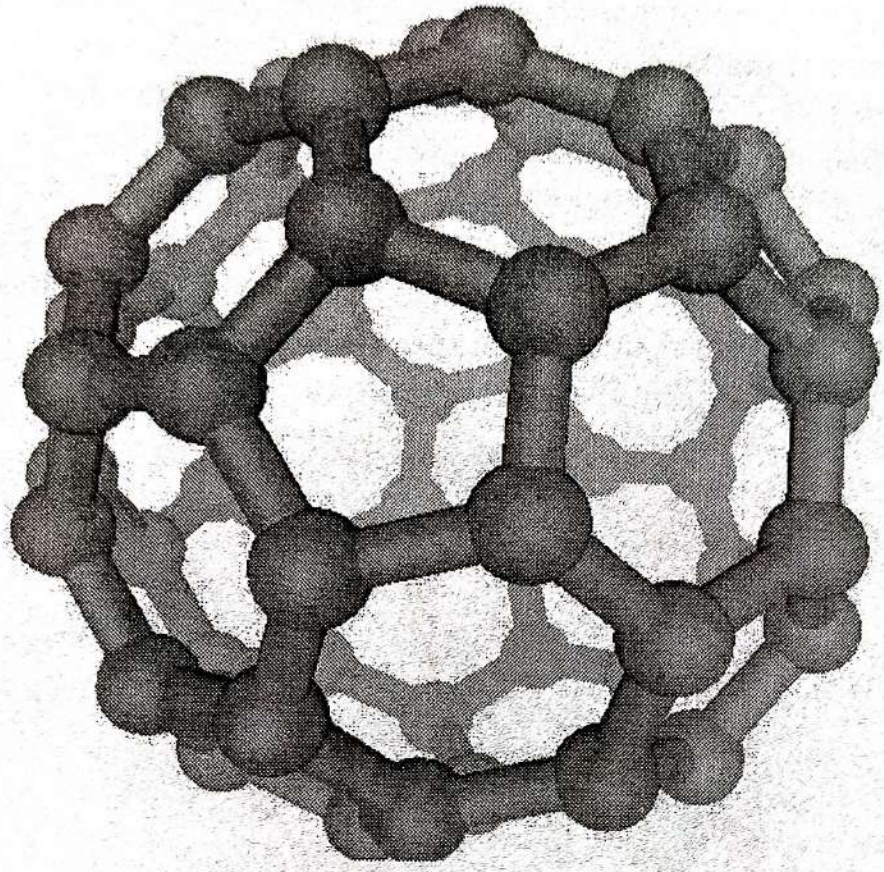

Fig. 6.4 : Fullerenes

When one is speaking about the fullerenes, one should mention an interesting property of these closed structures – the ability for holding the molecules inside (hence the fullerenes are potential nano - capsules). The nano – capsule is a closed nanostructure (the fullerene or the nanotube) with one or more atoms of the substance inside the structure. For the substance enclosed in the fullerene nano-capsule, carbon atoms act like a defense shield. The fullerene containers are good for protecting their contents from water and acid. Some interesting magnetic properties of the ferromagnetic metals (Fe, Co, Ni) inside the fullerenes were observed; namely, the magnetic properties of the metals remain unchanged.

The fullerenes have synthetic, pharmaceutical and industrial applications. Degenerative diseases and ordinary aging processes are caused by intracellular oxygen-free radicals with unpaired electron. C_{60} fullerene can react with radical species thus halting the process of aging. It can be used as facial moisturizer. Fullerene can act as a very good MRI contrast agent. They can also be used in light emitting diodes in different electronic equipments and computing. It can be used as additive to grease.

6.5 CARBON NANOTUBES

Carbon nanotubes discovered in 1991 by Iijima, are seamless cylinders composed of carbon atoms in a regular hexagonal arrangement, closed on both ends by hemispherical endcaps. They are allotropes of carbon. A single wall carbon nanotube is a one atom thick graphene sheet of graphite (called graphene) rolled up into a seamless cylinder with diameter of the order nanometer. Each nanotube is a single molecule composed of millions of atoms; the length of this molecule is much greater (on the order of thousands of times greater) than its diameter. This results in a nanostructure where the length to diameter ratio exceeds 10,000. Such cylindrical carbon molecules have novel properties that make them potentially useful in many applications in electronics, optics, nanotechnology and other fields of materials science. They exhibit extraordinary strength and unique electrical properties and are efficient conductors of heat.

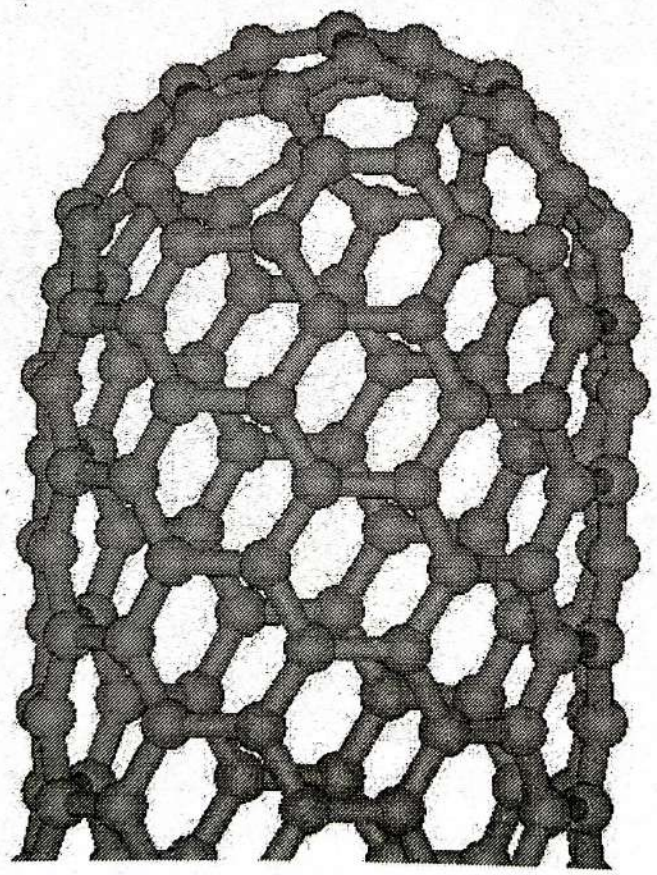

Fig. 6.5 ; Carbon Nanotube

Nanotubes are members of the fullerene structural family, which also includes buckyballs. Whereas buckyballs are spherical in shape, a nanotube is cylindrical, with atleast one end typically capped with a hemisphere of the buckyball structure. Their name is derived from their size, since the diameter of the nanotube is in the order of a few nanometers. (Approximately 50,000 times smaller than the width of a human hair). While they can be upto several millimeters in length.

There are two main types of nanotubes :

(a) Single-walled nanotubes (SWNTs)

(b) Multi-walled nanotubes (MWNTs)

The nature of the bonding of a nanotube is described by applied quantum chemistry, specifically, orbital hybridization. The chemical bonding of nanotubes are composed entirely of sp^2 bonds, similar to those of graphite. This bonding structure which is stronger than the sp^3 bonds found in diamond provides the molecules with their unique strength. Nanotubes naturally align themselves into "ropes" held together by Van der Waal's forces. Under high pressure, nanotubes can merge together trading some sp^2 bonds for sp^3 bonds, giving great possibility for producing strong unlimited length wires through high pressure nanotubes linking.

These nanotubes are extremely strong and stiff, and relatively ductile. For single-walled nanotubes, tensile strengths range between 50 and 200 GPa (approximately an order of magnitude greater than for carbon fibres); this is the strongest known material. Elastic modulus values are on the order of one tetrapascal [TPa (1 TPa = 10^3 GPa)], with fracture strains between about 5% and 20%. Furthermore, nanotubes have relatively low densities. On the basis of these properties, the carbon nanotube has been termed the "**ultimate fiber**" and is extremely promising as reinforcement in composite materials.

Properties:

Graphite could be bent to form MWCNTs with different helicities or chiralities which refer to the way hexagonal carbon rings are arranged with respect to the tubule axis. The structure of CNTs can be characterized using two indices 'm' and 'n'; in armchair CNTs 'm=n' and in zig zag CNTs n=0. In chiral, m and n are different. The electronic properties of SWCNTs depend on the chirality and the diameter. Armchair type nanotubes are electronic conductors whereas zig zag nanotubes are semi-conductors. Thus CNTs can be either metallic or semiconducting in their electrical behaviour. They can act as either conductors or semi-conductors depending on their chirality, possess an entrinsic superconductivity. Depending on the angle at which the graphite sheet is rolled up, called the roll-up vector, electrical transport in carbon nanotubes changes dramatically. Those tubes having a helical twist in their structure have semi-conducting properties while achiral tubes are metallic. MWNTs show complex conductivity.

There is no change in current across different parts of metallic single walled nanotubes. The conductivity and resistivity of ropes of single walled nanotubes have been measured by placing electrodes at different parts of the CNTs. They show resistivity of the order of 10^{-4} ohm-cm at 27°C proving to be the most conductive carbon fibre known.

The individual single walled nanotubes may contain defects which allow them to act as transistors. Thus, joining CNTs together may form transistor like devices.

CNTs show structural rigidity and flexibility. The carbon atoms of a single sheet of graphite form a planar honeycomb lattice. Each carbon atom is connected to neighbouring atoms via a strong chemical bond. Due to these strong bonds, the basal plane elastic modulus of graphite is having very high value.

MWCNTs possess a Young's Modulus around 1.8 TPa, which is 100 times larger than that of steel. It has been regarded as 100 times stronger than steel and six times lighter (weight wise).

The Young's moduli of order of 1.8 TPa is higher than conventional carbon fibres (about 800 Gpa). This high Young's modulus makes CNTs a very strong material. They are very resistant to damage from physical forces. Pressing on the tip of a nanotube will bend it without causing any damage. When the force is removed, the nanotube returns to its original. Thus CNTs are extraordinarily flexible and do not break upon mechanical deformation. For example, they can be bend mechanically by mechanical milling, or by embedding the tubes in a polymeric resin.

Applications:

The utility of carbon nanotubes is found mainly in molecular electronics or computers. They are used in field emission based flat panel displays. They can be used as chemical sensor and ultra-sensitive electromechanical sensors. They find application in novel semi-conducting devices. It is used in batteries and fuel cells. It is used as filling material in polymer composites. It is anticipated that future application of carbon nanotube will include diodes and transistors.

Comparison Between SWCNTs and MWCNTs:

Feature	SWCNTs (Single-Walled)	MWCNTs (Multi-Walled)
Structure	Made of a single layer of graphene rolled into a tube	Made of multiple layers of graphene concentric tubes
Diameter	0.4 to 2 nm	2 to 100 nm
Length	Up to several micrometres	Can be longer than SWCNTs
Electrical Properties	Can be metallic or semiconducting based on chirality	Generally metallic
Strength	Strong but less strong compared to MWCNTs	Stronger due to multiple layers
Thermal Conductivity	Higher than MWCNTs	Slightly lower than SWCNTs
Purity	Harder to synthesize with high purity	Easier to synthesize with higher purity
Cost	More expensive due to complex synthesis	Less expensive
Flexibility	More flexible and can bend easily	Less flexible
Applications	Used in transistors, sensors, and drug delivery	Used in composites, batteries, and coatings

6.6 APPLICATIONS OF NANOMATERIALS

Since nanomaterials possess unique, beneficial, chemical, physical and mechanical properties, they can be used for a wide variety of applications.

Medicines :

Nanoparticles offer some attractive possibilities in bio-medicine. They are smaller or of comparable size to that of a cell (10-100 μm), a virus (20-450 nm) or a protein (5-50 nm). They can therefore move more or less freely in an organism. They may be coated to make them compatible with, or bind to a biological entity of interest. Endothelian layers of fast growing tumour tissue are often quite porous so that these particles can penetrate relatively easily and can show specialized effect as a medicine.

Liposomes are relatively stable micelle-like structures built from suitable amphiphilic block co-polymers or by self-assembly from phospholipids. They are already in use for drug delivery. Drug molecules may be intercalated in the lipophilic wall that mimics a cell membrane. The liposome protects the drug from being metabolized in certain environments. Due to its more hydrophobic character, it may let it pass barriers between the digestive system and the blood or between blood and brain. When it arrives at the target site, the drug may be released due to a different pH or an enhanced temperature in an inflamed region. The pH of tumour tissue has values of 4-5. In liposomes when the pH can reach values as low as 4-5, liposomes open up or protective cells are removed, permitting the drug to be released where it is needed.

Ferromagnetic nanoparticles have also been developed for targeted delivery of therapeutic drugs, genes or radionuclides. The magnetic component of these carrier particles (like magnetite, Fe_3O_4 or maghemite γ-Fe_3O_3) is coated with a shell of SiO_2 and then by a bio-compatible polymer. They can be fucntionalised to provide attachment points for the coupling of cytotoxic drugs or bind anti-bodies to the carrier complex. A magnet is placed outside the body near the target site to capture the magnetic particles flowing in the circulatory system. The action of cytostatic anti-cancer drugs is localized and reduced unwanted side effect of anti-inflammatory drugs on patients who suffer on chronic arthritis. Dextrane coated iron oxides are bio-compatible and are extracted via the liver after the treatment.

Catabolism of tumours can be enhanced by artificially induced hyperthermia. This technique involves dispersing magnetic particles throughout the target tissue. It applies an alternating magnetic field of sufficient strength (0-15 kA m^{-1}) and frequency (0.05-1.2 MHz). If the temperature of the surrounding tissue can be maintained above a therapeutic threshold of 42°C for 30 minutes or more, then the cancer is destroyed.

In bio-medicine, it is advantageous to separate out specific biological entities from their native environment in order to prepare concentrated samples for analysis. This may

be achieved by tagging these entities like red blood cells, lung cancer cells, bacteria and urological cancer cells with magnetic particles coated with immunospecific agents. These cells are then removed in a fluid flow based magnetic separation device.

Another application of magnetic nanoparticles is that of contrast enhancement agent for magnetic resonance imaging. They shorten the relaxation time, both T_1 and T_2. The uptake of the nanoparticles by the tissue depends on their size. Larger particles with a diameter 30 nm or more are collected by the liver and spleen. Smaller particle of 10 nm or less are collected in reticuloendothelial cells throughout the body, including those of lymphnodes and bone marrow. As tumour cells do not have the effective reticuloendothelial system of healthy cells, their relaxation times are not altered. Thus, the identification of lymphnodes liver tumors and brain tumour can be done.

Another application of nanomaterials involves the coating of endoimplants with bio-compatible layers. It forms a dense and mechanically stable interface between the biological tissue and the incompatible metallic materials. Medical implants such as orthopedic implants and heart valves are made of titanium and stainless steel alloys. These alloys are used in human as they are bio-compatible, i.e. they do not adversely react with human tissue. In the case of orthopedic implants, these materials are relatively non-porous. For an implant to effectively mimic a natural human bone, the surrounding tissue must penetrate the implants. Since these materials are relatively impervious, human tissue does not penetrate the implants, thereby reducing their effectiveness. Nanocrystalline zirconia (zirconium oxide) ceramic is hard, wear resistance, corrosion resistant, and bio-compatible. Nanoceramics can also be made porous into areogels, if synthesized by sole-gel techniques. This results in far less frequent implant replacements. Nanocrystalline silicon carbide (SiC) is used for artificial heart valve due to its low weight, high strength, extreme hardness, wear- resistance, inertness and corrosion resistance.

Environmental Technologies :

Nanomaterials have not yet been explored much in view of their potential use to solve environmental problems.

Nanomaterials may also be important for environmental sustainability. Environmental benefits may include better means for an improved and more efficient power supply, leading to the conservation of nature and natural resources, a reduction in air pollution and indirectly to a sustainable environmental protection.

Nanoporous aluminosilicates (zeolites) are already being used as adsorbents to bind radionuclide and poisonous transition metal ions from waste water because of their high adsorption capacity and the tuneable selectivity.

Nanocrystalline materials possess extremely large grain boundaries relative to their grain size. Due to their enhanced chemical activity, nanomaterials can be used as catalyst

to react with such noxious and toxic gases as carbon monoxide and nitrogen oxide in automobile catalytic converters and power generation equipment to prevent environmental pollution arising from burning gasoline and coal.

Nanoporous membranes are based mostly on zeolites or on tailored polymer membranes containing sintered nanoparticles with adjustable pore size. They are used to filter micro dust particles out of the air and water with more efficiency than traditional filter materials. They permit the inclusion and immobilization of catalytically active metal oxide centers or of biocatalysts to directly degrade problematic pollutants such as chlorinated ethenes. This technology invites for future applications like potable water and separation of viruses and bacteria.

Prominent new materials like gold nanoparticles are used for the degradation of toilet odours. Titanium dioxide is used as coating for the shielding of electrical lights in tunnels. By converting deposited soot particles to carbon dioxide, it keeps the shielding transparent. Zinc oxide serves as a photocatalyst for the degradation of chlorinated phenols. In near future, the walls of swimming pools will be coated by an ultra thin layer of photocatalytically active materials. Activation of oxygen leads to the formation of hydroxyl radicals. These hydroxyl radicals are anti-bacterial agents and can degrade many organic compounds.

Nano based sensor materials (metals, semi-conductors, polymers) is deposited on selected areas of a chip. It serves to analyze gas mixture by measuring solubility, vapour pressure, melting point, boiling point or heats of adsorption or reaction of the components.

Catalyst :

Nanoparticles have a much greater surface area per unit mass compared with larger particles. As growth and catalytic chemical reactions occur at surfaces, this means that a given mass of material in nanoparticulate form will be much more reactive than the same mass of material made up of larger particles. With the help of nanotechnology, it is possible to synthesize metal nanoparticles in solution in the presence of a surfactant to form highly ordered monodisperse films of the catalyst nanoparticles on a surface. It renders more uniformity in the size and chemical structure of the catalyst which, in turn, leads to greater catalytic activity. There is always the production of fewer byproducts. These more active and durable catalysts find the application in cleaning up waste streams.

Nanomechanics :

Molecules are being developed, which can change conformation upon stimulation by temperature, pH, light or electron transfer and act as nanomanipulators, nanomuscles or for the storage information.

Recently, a nanoscale electromechanical motor consisting of a 300 nm rectangular gold blade that sits on a multiwall nanotube axle was functionalized. It was demonstrated by scanning electron microscopy that the metal blade changes its orientation as a function of the electrical voltage applied to the stator electrodes. Future applications for this device include deflectable mirrors or sensor paddles for the detection of the motion of micro-fluidic systems.

A thermally driven single-molecule nanocar with a fullerene based wheel-like rolling motion is reported.

Many applications of nanomaterials are based on carbon nanotubes (CNTs). They are mechanically very strong and stiff as diamond but are highly flexible. Depending on the helicity of the graphene sheet they are semi-conducting or metallic. In a hot drawing process inspired from textile technology, wet-spun composite fibres consisting of single and multiwall CNTs and polyvinyl alcohol with a diameter of 30 μm and a length 10m can be produced. Their tensile strength is found to be between 1.4 and 1.8 GPa. They hold great potential for a number of applications such as bullet proof vests, protective textiles, helmets etc.

Each entity of a living cell is described as a living machine. Nanotechnology builds nanomachines that are more efficient than conventional machines. They are self assembling, self-curing, self-replicating and they adapt their production to the actual needs.

When small amounts of tin are deposited on a Cu(111) single crystal surface at 290 K it is observed that the tin crystal proceed to move spontaneously along the surface in a systematic fashion, leaving bronze alloys in their tracks. Tin atoms randomly exchange with copper atoms in the surface. The exchanged copper atoms are ejected in the form of an ordered 2-D bronze crystals. The motion is driven by the lowering of the surface free energy by alloying. When the island meets a track, they do not cross, instead they change direction of this allows them to move over an unalloyed region of the surface. The driving force of the motion could be used to drive nanomotors.

Cutting tools made of Nanocrystalline materials, such as tungsten carbide, tantalum carbide and titanium carbide are much harder, more wear resistant, erosion resistant and last longer than their conventional counter parts. They also enable the manufacturer to machine various materials much faster, thereby increasing productivity and significantly reducing manufacturing cost. Also, for the miniaturization of micro electronic circuits, the industries need microdrills (drill bits with diameter less than the thickness of an average human hair or 100 μm) with enhanced age retention and far better wear resistance. Since nanocrystalline carbides are much stronger, harder and wear-resistant, they are currently being used in these microdrills.

Nanoelectronics :

The best way to increase the speed at which electric charges work is to decrease the distance they have to travel. It is predicted that the number of transistors per unit area on a microchip will double every year. But there is an unavoidable limit for this growth. A time at which the space to store 1 bit becomes about 4 nm, troublesome quantum behaviour starts. Heat produced creates a huge problem and neighbouring bits would interact so that the independence of bits would be lost.

A bit is encoded by the presence or absence of a silicon atom inside a unit of $5 \times 4 = 20$ atoms, with the remaining 19 atoms required to prevent adjacent bits from interacting with each other. The storage density of magnetic hard disk is increased.

Already in commercial productions are high-efficiency, very bright and colourful thin display based on organic light emitting devices (OLEDs). Significant progress is also being made in the realization of thin film transistors and thin film organic photovoltaic cells.

Low Cost Flat Panel Displays :

Flat panel displays represent a huge market in the laptop (portable) computers industry. By synthesizing nanocrystalline phosphorous, the resolution of these display devices can be greatly enhanced and the manufacturing cost can be significantly reduced. Also the flat panel display constructed out of nanomaterials possesses much higher brightness and contrast than the conventional ones owing to their enhanced electrical and magnetic properties.

High Energy Density Batteries :

Conventional and rechargeable batteries are used in almost all applications that require electric power. These applications include automobiles, laptop computers, electric vehicles, personal stereos, cellular phones, cordless phones, toys and watches. The energy density (storage capacity) of these batteries is low and requires frequent charging. Nanocrystalline material synthesized by sole-gel techniques are candidates for separator plate in batteries because of their aerogel structure which can hold considerably more energy. Nickel metal hydride (Ni-MH) batteries made of nanocrystalline nickel and metal hydrides are designed to require less frequent recharging and to last much longer.

High Power Magnets :

The strength of a magnet is measured in terms of coercivity and saturation magnetization values. These values increase with a decrease in the grain size and an increase in the specific surface area of the grains. Magnets made of nanocrystalline yttrium-samarium-cobalt grains possess unusual magnetic properties due to their extremely large surface area. Typical applications for these high power rare earth magnets include automobile alternators, land based power generators, motors for ships, ultra sensitive analytical instruments and magnetic resonance imaging (MRI) in medical diagnosis.

6.7 REVIEW QUESTIONS

1. What are nanomaterials?

Ans. Refer Section 6.1.

2. Why the properties of nanomaterials differ from the conventional materials?

Ans. Refer Section 6.1.

3. State the structural details of graphite.

Ans. Refer Section 6.2.

4. What are carbon nanotubes?

Ans. Refer Section 6.5.

5. Discuss the application of nanomaterials in medicines.

Ans. Refer Section 6.6.

6. What are the applications of nanomaterials in the field of environmental technology?

Ans. Refer Section 6.6.

7. Explain the structure of fullerene.

Ans. Refer Section 6.4.

8. How nanomaterials can be used in the field of mechanics?

Ans. Refer Section 6.6.

9. Give the applications of nanomaterials in electronic and its related field.

Ans. Refer Section 6.6.

10. Write a short note on Graphene.

Ans. Refer Section 6.3.

11. Give the applications of Graphene.

Ans. Refer Section 6.3.

12. Give the properties of Graphene.

Ans. Refer Section 6.3.

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